1983

General purpose electronic test equipment (GPETE) acquisition considerations for automated calibration.

Stahler, William D.

Monterey, California. Naval Postgraduate School

Report Number----- NPS54-83-002

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

GENERAL PURPOSE ELECTRONIC TEST EQUIPMENT (GPETE)
ACQUISITION CONSIDERATIONS FOR AUTOMATED CALIBRATION

by

William D. Stahler

June 1983

Thesis Advisor: J. W. Creighton

Prepared for:
Naval Air Systems Command
Washington, D. C. 20361

NAVAL POSTGRADUATE SCHOOL
Monterey, California

Rear Admiral J. J. Ekelund
Superintendent

David A. Schrady
Provost

This thesis prepared in conjunction with research supported in part by the Naval Air Systems Command.

Released as a
Technical Report by:

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NPS54-83-002	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) General Purpose Electronic Test Equipment (GPETE) Acquisition Considerations for Automated Calibration		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis June 1983
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) William D. Stahler		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Air Systems Command Washington, D. C. 20361		12. REPORT DATE June 1983
		13. NUMBER OF PAGES 125
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

automated calibration; calibration; electronic test equipment; general purpose electronic test equipment (GPETE)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Calibration is a vital logistics element that directly impacts operational readiness and mission capability. Declining manpower resources and fleet expansion necessitate improvements in calibration productivity. The Navy has initiated several calibration automation programs. Realization of the full potential of automated calibration systems requires that the test instrument be IEEE-488 general purpose interface bus (GPIB) configured.

This thesis examines the relative costs and benefits of configuring general purpose electronic test equipment (GPETE) with GPIB to facilitate automated calibration. It does so through the development of a simple cost-benefit analysis and a discussion of non-quantifiable advantages and disadvantages, based upon extensive interviews with experts and literature research. In general, the analysis supports GPIB procurement when procurement quantities are large, calibration procedures are lengthy, and/or the calibration interval is short.

Approved for public release; distribution unlimited.

General Purpose Electronic Test Equipment (GPETE) Acquisition Considerations for Automated Calibration

by

William D. Stahler
Lieutenant Commander, United States Navy
B.S., University of Illinois, 1971

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
June 1983

ABSTRACT

Calibration is a vital logistics element that directly impacts operational readiness and mission capability. Declining manpower resources and fleet expansion necessitate improvements in calibration productivity. Toward this end the Navy has initiated several calibration automation programs. Realization of the full potential of automated calibration systems requires that the test instrument be IEEE-488 general purpose interface bus (GPIB) configured. This thesis examines the relative costs and benefits of configuring general purpose electronic test equipment (GPETE) with GPIB to faciliate automated calibration. It does so through the development of a simple cost-benefit analysis and a discussion of non-quantifiable advantages and disadvantages, based upon extensive interviews with experts and literature research. In general, the analysis supports GPIB procurement when procurement quantities are large, calibration procedures are lengthy, and/or the calibration interval is short.

TABLE OF CONTENTS

LIST OF FIGURES

I. INTRODUCTION

The author's assignment as the Avionics/Armament (IM-3) Division Officer onboard USS JOHN F. KENNEDY (CV-67) brought an acute awareness of the criticality of electronic calibration to the mission effectiveness of an aircraft carrier (CV) and its embarked airwing. Virtually every item of electronic test equipment requires calibration. Therefore, any factor that affects calibration productivity and turnaround time will have a direct effect on both electronic test equipment and electronic system availability.

USS JOHN F. KENNEDY was fortunate to be assigned a number of highly skilled and highly motivated calibration technicians. But, in spite of this advantage, calibration still often created a "bottleneck" in the electronic/avionics component repair cycle. Other CVs were not as fortunate and experienced far greater difficulties.

Improved local management emphasis and planning is required to optimize the utilization of available calibration resources. On USS JOHN F. KENNEDY several competent avionics technicians were reassigned from other areas to the onboard Fleet Calibration Activity (FCA); on-the-job training (OJT) was arranged at local Naval Air Rework Facility (NARF) and shore based Aircraft Intermediate Maintenance Departments (AIMD); and detailed calibration planning was introduced. Yet these measures were not enough. Even in the current favorable (in terms of technician numbers and skill levels) peacetime environment, the CV FCAs are hard pressed to provide the calibration/repair quality and throughput required to optimize weapons system support.

The passing of the "post war baby boom" generation and resultant decrease in the number of young men from which the Navy can recruit (figure 1.1) and increasing lucrative private sector opportunities for skilled electronics technicians promises to aggravate this problem at a time that the Navy is expanding to a six hundred ship fleet based upon fifteen carrier battle groups.

The Navy generally recognizes the current calibration shortcomings and trends. As the result several effective programs have been initiated. However, one aspect that has been largely overlooked is the influence that test equipment configuration has upon the calibration facility's productivity. It is upon this aspect that this thesis will concentrate.

The objectives of this thesis are:

1. To provide a basic understanding of the Navy GPETE program and the IEEE-488 interface bus.
2. To analyze the costs, benefits, advantages, and disadvantages of the IEEE-488 configuration of GPETE.
3. To make recommendations for the enhancement of fleet calibration productivity.

Toward this end, Chapter 2 will present various past and present calibration productivity and workload reduction initiatives. Chapter 3 will provide a brief introduction to the Navy General Purpose Electronic Test Equipment (GPETE) program while Chapter 4 gives an overview of the IEEE-488 interface bus. Chapter 5 presents the centerpiece of this thesis, a cost-benefit analysis of GPETE IEEE-488 configuration. Chapters 6, 7 and 8 will provide related issues, recommendations and an epilogue respectively.

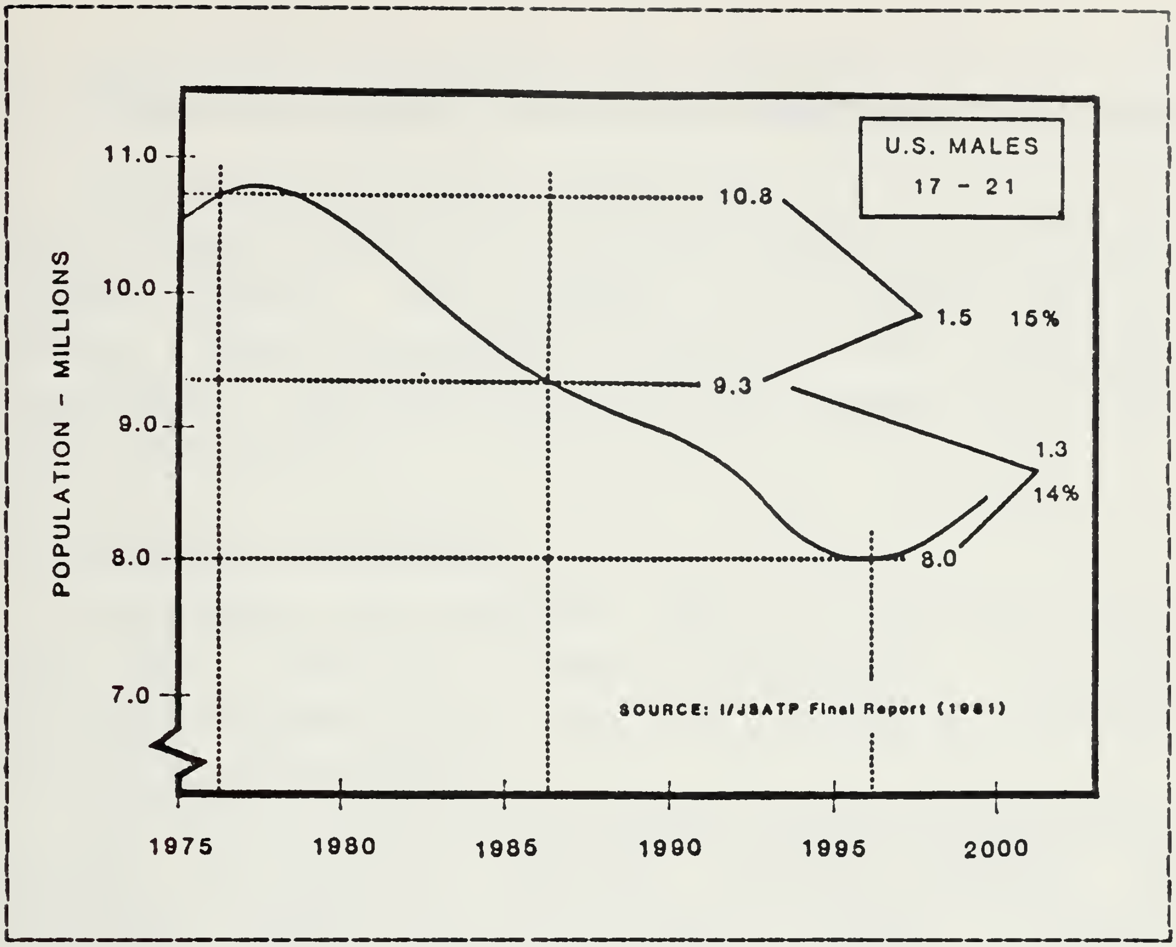


Figure 1.1 Military Population Resources.

This figure demonstrates the decreasing manpower resources from which the Navy will be recruiting over the next two decades. From a high of 10.8 million in 1976, the number of males 17-21 years of age in the population of the United States has declined to approximately 10.0 million in 1983 and is projected to reach a low of 8.0 million in 1996. [Ref. 1]

II. CURRENT CALIBRATION PRODUCTIVITY ENHANCEMENT INITIATIVES

Calibration productivity enhancement and workload reduction has been the objective of several Navy initiatives over the past decade. These programs can be divided into two general areas- calibration automation and management improvement. The following is a brief summary of some of these initiatives.

A. CALIBRATION AUTOMATION

As automatic test equipment (ATE) has improved technician test, check and repair productivity, automated calibration systems (ACSs) have the potential of improving calibration productivity.

The Navy is currently approaching calibration automation through four different programs: Modularly Equipped and Configured Calibrators and Analyzers (MECCA), Automated Calibration and Diagnostics (AC/D)-formerly Automated Calibration Laboratory/ Satelite Calibration and Diagnostics (ACL/SCD), Mobile Automated Calibration Laboratory (MACL), and Parametric Tolerance Verification.

1. MECCA

MECCA is a portable, automated calibration system developed by the Metrology Engineering Center (MEC). The system consists of a micro-processor driven controller (currently the FLUKE 1720A/AP) linked by interface bus to one of several programmable calibrators (meter, signal generator, oscilloscope and frequency/counter calibrators are currently available or under development). MECCA is able to function in one of two modes of operation depending on the test instrument's (TI) IEEE-488 configuration.

In the "open loop" mode (for non-IEEE-488 test instruments) the controller and calibrator are interfaced via the IEEE-488 bus permitting the controller to automatically set the calibrator's function, range and accuracy. However, because the test instrument is not bus compatible, its interface with the controller consists of standard leads. Therefore, the operator must physically interface with the test instrument and controller (using the controller's hand held "operator's aid") to adjust the calibrator's output until the test instrument's measurement indication (digital or dial display) coincides with the controller's programmed output. Once this is accomplished, the controller is able to compare the calibrator's programmed and adjusted outputs to determine if the test instrument is within the prescribed tolerance.

In the "closed loop" mode (for IEEE-488 configured test instruments) operator interface is significantly reduced. Because the test instrument is now interfaced with the controller and the calibrator via the IEEE-488 bus, the controller can make direct comparisons of the calibrator's output and the test instrument's measurement indication. Therefore, operator adjustment of the calibrator output is eliminated.

While it is possible for a "closed loop" calibration to automatically proceed from one parametric test to another, Navy closed loop procedures are currently written to display the results of each parametric test on the controller CRT. Each step in the calibration procedure must, therefore, be manually initiated by the operator.

2. AC/D

AC/D is a Naval Aviation Logistics Center (NALC) program designed to encourage and coordinate the development of automated calibration systems (ACSs) in Navy type II and

type III calibration laboratories. The program is managed by NALC Code 330 with contractor support services (CSS) provided by Science Applications Inc.'s (SAI) Calibration Support Division. Initially the program only included three calibration facilities: Naval Air Test Center (NATC) Patuxent River, NARF Pensacola Type II, and NARF Alameda Type II.

NATC Patuxent River is assigned responsibility for the development of ACSs. Like MECCA, the AC/D systems are based on a microprocessor based controller and programmable calibrators. But unlike MECCA, AC/D procedures are written to minimize operator intervention. Instead of requiring the operator to initiate each step, AC/D procedures are, whenever possible, "hands off" with the results directly transmitted to a printer to facilitate review at the operator's convenience. Thus, following set-up and program initiation, a fully programmable TI could run through the entire calibration procedure without the operator being present. To date, NATC has developed several ACSs including an AN/APM-403, radar altimeter test set, ACS that reduces calibration requirements from forty high skill manhours to 8-12 moderate skill manhours [Ref. 2].

NARF Pensacola is tasked with the development of systems to detect and diagnose faults in the test instrument's IEEE-488 bus, interconnecting, and conventional circuitry and the instrument's microprocessors. An IEEE-488 bus diagnostic system based upon an Interface Technologies ITC-488 controller has been developed and deployed to the type II and III (but not FCA (type IV)) laboratories. A microprocessor diagnostic system is near completion and current planning calls for type II/III deployment in September 1983. Current plans call for initiating the development of diagnostics for instrument interconnecting and conventional circuitry in the near future. [Ref. 3]

NARF Alameda is assigned as the AC/D control center and, as such, tasked with the production and distribution of the systems developed by the other facilities.

At the AC/D Conference in Dallas, Texas 29-31 March 1983, the remaining NARF type II and type III laboratories were brought into the program. The addition of these activities and their resident expertise (many have independently developed ACSs) promises to further enhance ACS development and application.

Because all of the AC/D laboratories have FLUKE 1720A controllers, many of the ACSs developed under this program will be directly applicable to MECCA.

3. MACL

The MACL program was initiated in 1981 by NALC under contract to SAI at NATC Patuxent River. The program's objective is the development of a mobile automated calibration facility that can be rapidly deployed to a forward site or used to temporarily augment an existing facility.

MACL is housed in a 9' X 28' trailer that is configured with all necessary power, air conditioning, racks and benches. The installed ACS (called Mobile Automated Calibration System (MACS)) is based on a John Fluke 7405A meter calibrator, modified by the addition of a Tektronix oscilloscope calibrator. Unlike MECCA, whose applications software and ICPs are stored on floppy diskettes, MACS stores all its software in a computer for direct access by the system controller.

The MACL program includes more than the development of MACL calibration capability and logistics. It also includes tasks such as the development of a universal calibration procedure generator that will have wide ACS applicability. [Ref. 4]

4. Parametric Tolerance Verification

Parametric tolerance verification is a calibration concept being implemented in the latest generation of Navy ATE. Instead of individually calibrating ATE building blocks (BBs) off-line, the station as a whole is certified using a primary reference standard and automated program.

The reference standard may be integrated into the station as either an imbedded building block (BB) or as a plug-in interface device (ID). The former configuration will be implemented in the AN/USM-470 Automatic Test Station (ATS) and the AN/USM-484 Hybrid Test Station (HTS). The latter configuration is planned for the AN/USM-469 RADCOM and the AN/USM-429(V)1 CATIIID.

Parametric tolerance verification reduces FCA workload requirements by reducing the number of station building block (BB) test instruments requiring off-line calibration. For example, of the 23 AN/USM-470 building blocks, only one (the calibration module itself) requires off line calibration. [Ref. 5] Additional advantages of parametric tolerance verification include:

1. Enhancement of ATE operational readiness by eliminating BB removals at individual calibration intervals.
2. Checking of remote/programmable features.
3. Testing of instruments in their operational environment.
4. Reduction of BB in transit time and damage.
5. Reduction of connector wear by reducing BB removal requirements.
6. Elimination of the calibration of unused features and accuracies.

5. Miscellaneous ACS Initiatives

Virtually every Navy civilian manned calibration facility, whether involved in AC/D or not, has their own automatic calibration initiatives and many have some operational systems. The author found such programs in force at Navy Calibration Laboratory (NCL) Tustin, NCL Whidby Island, the Naval Avionics Center (Indianapolis), and several NARF calibration laboratories which until recently had not participated in AC/D.

B. MANAGEMENT IMPROVEMENT

1. Intervals By Exception

"Intervals By Exception" is a management decision making approach to calibration interval determination and interpretation developed by MEC in 1970. The approach differs from past model number and serial number interval determination criteria by isolating individual serial numbers whose statistical reliability differs markedly from their model's population norm. The individual deviant instruments (termed "dogs" if significantly less reliable than the norm and "gems" if significantly more reliable) are assigned individual calibration intervals (published in the "Metrology Bulletin" distributed monthly by MEC). The remaining population reliability data is used to determine a model calibration interval for semi-annual publication in the "Metrology Requirements List" (METRL), NAVAIR 17-35MTL-1.

Isolation of these "exceptions" increases the model's calibration interval, thus reducing the total number of required calibrations. A test program of 60 "high submission" model numbers demonstrated an average interval increase from 6.8 to 8.2 months as the result of this program. [Ref. 6]

2. MEC AOP Program

In 1976 the Metrology Engineering Center changed its calibration interval criteria from .85 EOP (end of period) to .85 AOP (average over period). The results in terms of increased calibration intervals were dramatic. From June 1976 to July 1979 the average calibration interval of a sample of 305 GPETE items increased from 8.8 to 13.6 months. The estimated annual savings resulting from this increase was 18,000 calibrations and 45,000 manhours. [Ref. 7] By October 1982 the average interval of these same 305 items had increased to 15.1 months [Ref. 8].

3. PME Work Center Productivity Enhancement Program

The Precision Measuring Equipment (PME) Work Center Productivity Enhancement Program was initiated by the Aircraft Intermediate Maintenance Support Office (AIMSO) in 1981. The purpose of this program is to improve the productivity of NAVAIR type IV (FCA) calibration activities through the identification of depot level (type I, II, and III calibration laboratories) calibrations that are within the capability of the forwarding FCA. A survey of ten FCAs identified approximately 25,000 calibration hours in this catagory. [Ref. 9]

AIMSO proposes generation of a quarterly or semi-annual report to identify these inappropriate depot level calibrations. This report, which would be distributed to the cognizant FCA manager, AIMD Officer and type commander, would be used to investigate the causes of the problem (inadequate screening, training, calibration standards, etc.) so that corrective action could be initiated.

Elimination of inappropriate depot level calibrations will reduce test equipment turnaround time and save an estimated $15 million in NARF Naval Industrial Funds (NIF)

annually. Additional NIF savings could be realized by extension of such a program to NAVSEA and NAVELEX cognizant activities. [Ref. 10]

III. GENERAL PURPOSE ELECTRONIC TEST EQUIPMENT (GPETE)

Navy electronic test equipment is generally classifed as either automatic test equipment (ATE), calibration standards, or electronic test equipment (ETE). ATE consists of systems of instruments interfaced with a computer (controller) to work as a unit in performing test functions. Calibration standards are those instruments which have been certified to serve as the accuracy control in the calibration of other instruments. ETE refers to manually operated, stand alone instruments. In recent years, with the introduction of microprocessor controlled instruments and automated calibration systems, these distinctions have become increasingly clouded.

The Navy sub-divides ETE into three general catagories: general purpose electronic test equipment (GPETE), special purpose electronic test equipment (SPETE), and other ETE (catagory definitions are provided in Appendix B). Of the three, GPETE contains the greatest number of individual instruments. In fact, the calibration of GPETE accounts for over half of the electronic calibration workload in a CV FCA [Ref. 9].

A. GPETE CLASSIFICATIONS

GPETE is sub-divided into the following two classifications:

1. Standard GPETE

Standard GPETE is equipment which has been determined by the Naval Electronic Systems Command to most closely meet Navy requirements. This equipment, which

consists primarily of off-the-shelf (OTS) commercial test equipment (CTE), is listed in MIL-STD-1364 (Navy) as preferred for procurement and is approved for service use.

2. Non-Standard GPETE

Non-standard GPETE are those items of GPETE not listed in MIL-STD-1364 as preferred for procurement. This catagory includes standard GPETE instruments whose configuration (options) differ from the prime configuration listed in MIL-STD-1364 Appendix I.

B. GPETE MANAGEMENT

Prior to the issue of NAVMAT Instruction 5430.42 (superceded by the NAVMATINST 4790.25 series), on 15 April 1970, GPETE management was fragmented among the hardware systems commands. This instruction assigned Navy-wide GPETE management responsibility to NAVELEX. NAVELEX responsibility was subsequently expanded to include overall Test, Measuring, and Diagnostic Equipment (TMDE) management by NAVMAT Notice 5430 of 29 June 1981. This latest change was facilitated by the transfer of the Test and Monitoring Systems (TAMS) Office from NAVMAT (where it was code 04T) to NAVELEX (where it is code C8T).

Within NAVELEX GPETE responibilities are assigned to the TMDE Division (Code 815) where they are delegated to two branches. The Test Equipment Maintenance Engineering Branch (Code 8152) acts as the test equipment Logistics Element Manager (LEM) and is assigned GPETE responsibilities related to NAVELEX cognizant prime weapons systems. The Test Equipment Engineering and Procurement Branch (Code 8151) is responsible for Navy-wide GPETE program management (less logistics).

1. <u>NAVELEX 8151 Responsibilities</u>

The Test Equipment Engineering and Procurement Branch is staffed with acquisition engineers and a single program analyst. It is tasked with the following GPETE management responsibilities:

1. <u>Classification of ETE</u>. ETE is classified as GPETE, SPETE or other ETE by the Naval Material Command's Electronic Test Equipment Classification Board. A NAVELEX 8151 representative chairs this board and resolves classification through telephone coordination. Only occasionally is a formal meeting required. [Ref. 11]
2. <u>Quality and Specifications</u>. NAVELEX 8151 carries out its quality and specification responsibilities through the maintenance of the following three standards:
   a) MIL-STD-1364, "Military Standard for Standard General Purpose Electronic Test Equipment." A companion document, MIL-STD-1387, provides procedures for procurement approval of non-standard GPETE.
   b) MIL-T-28800, "General Specification for Test Equipment for Use With Electrical and Electronic Equipment"
   c) MIL-HDBK-265, "Standard General Purpose Electronic Test Equipment Support Items (GSI)"

   Technical support for maintenance of these standards is provided by the Test Equipment Environmental Compatibility Division (Code 026) at the Naval Electronic Systems Engineering Activity (NESEA).
3. <u>GPETE Procurement Coordination</u>. NAVELEX 8151 is the liaison between the GPETE users/buyers (the hardware systems commands) and the GPETE procuring agency

(SPCC). In this role NAVELEX 8151 is responsible for:

a) Maintenance of an automated data base that includes requirements identification, procurement plans and budgeting inputs.

b) Preparation of specifications ("salient characteristics") for GPETE procurement.

c) Recommendation of procurement methods.

d) Review, clarification, coordination, technical approval, and consolidation of hardware systems command (SYSCOM) GPETE requirements lists. [Ref. 12]

4. <u>GPETE Planning and Budgeting</u>. NAVELEX 8151 prepares CPN Program Objectives Memorandums (POM) relative to the GPETE program and the subsequent budget forecasts.

5. <u>Standardization</u>. NAVELEX 8151 responsibilities for standardization include:

a) Development and implementation of a GPETE standardization program which minimizes proliferation and ensures total cost effectiveness without degrading mission performance.

b) Assurance that standard GPETE models listed in MIL-STD-1364 (Navy) are up to date and minimize life cycle costs by considering overall reliability, maintainability, repair, calibration and ILS planning.

c) Control of non-standard GPETE procurement through management of MIL-STD-1387 procedures.

d) Centralization of procurement to the maximum extent possible. [Ref. 13]

2. NAVELEX 8152 Logistic Responsibilities

In addition to the TMDE management responsibilities for shore commands (discussed below), NAVELEX 8152 is the logistics element manager (LEM) for GPETE. As such, its responsibilities include:

1. Development of GPETE ILS.
2. Development of operational logistics support plans (including repair, calibration, provisioning and training) for GPETE.
3. Assignment of source, maintenance and recoverability (SM&R) codes to GPETE.

3. Hardware Systems Command Responsibilities

The hardware systems commands (SYSCOMs), as the TMDE managers for weapon systems under their cognizance, are assigned the following GPETE management functions:

1. Providing NAVELEX with GPETE requirements data, including the minimum performance specifications, to support weapon systems under their cognizance.
2. Consolidation and submission of GPETE initial outfitting (GINO) requirements.
3. Budgeting and funding identification of cognizant GINO requirements.
4. Development, maintenance and distribution of TMDE allowance and inventory lists for applicable user activities.
5. Designation of a representative to serve on the NAVMAT ETE Classification Board. [Ref. 14]

The specific SYSCOM areas of responsibility and internal GPETE management assignments follow.

a. Naval Air Systems Command

NAVAIR is the TMDE manager for aviation ground support equipment (GSE). Within NAVAIR, Code 552 (currently assigned to Code 55223) is responsible for GPETE management, but most GPETE functions have been delegated to the Naval Air Engineering Center (NAEC) Code 92524 [Ref. 15].

b. Naval Sea Systems Command

NAVSEA is the TMDE manager for ships and fleet activities ashore less aviation GSE. GPETE management within NAVSEA is assigned to the Weapons System Engineering Division (Code 06C) where it is carried out by NAVSEA Code 06C1C (Support Equipment Logistics Manager). Some GPETE management functions are performed in house, but all routine functions have been delegated to Naval Weapons Station, Earle.

c. Naval Electronics Systems Command

NAVELEX 8152 serves as the TMDE manager for shore activities less fleet activities ashore and aviation GSE. Many of the routine functions have been delegated to NESEA Code 026, who is assisted by a contractor [Ref. 16].

C. GPETE FUNDING

1. GPETE Initial Outfitting (GINO)

GINO funding is provided by the appropriate OPNAV program sponsor. NAVSEA and NAVELEX GPETE funding is appropriated under Other Procurement, Navy (OPN). NAVAIR GPETE funding is appropriated under Aircraft Procurement, Navy (APN).

In the OPN funding arena, GPETE funding is "fenced" (cannot be spent on anything else) and is, therefore, not readily susceptible to reduction. APN GPETE funding, on the other hand, is "unfenced" and, on occasion, has been reduced to facilitate other APN requirements. [Ref. 17]

2. GPETE End Item Replacement (GEIR)

Unlike GINO, GEIR is funded under Operations and Maintenance, Navy (O&MN) and comes directly out of the operating activity's Aviation Fleet Maintenance (AFM) or Supply and Equipage (S&E) funds. Whenever an item of GPETE is beyond the repair capability of the custodian, the item is to be turned into the supply system and a replacement drawn at the current Navy Stock Fund (NSF) GEIR price (averaging approximately 44% of the NSF GINO price for a new item) [Ref. 18].

Fleet activities have displayed some reluctance to use the NSF system. Complaints include high NSF prices, long replacement lead times, and the marginal quality of the replacement units (with no warranty). As a result, many activities have arranged repair at the manufacturer's service facility and, for a smaller charge, been ensured quality workmanship, reliability updates, a 90 repair warranty, a full Navy acceptable calibration, and relatively rapid turnaround. [Ref. 19]

These fleet complaints are not unfounded. The GPETE (7Z COG) system availability was only 36.4% during fiscal year 1982 and 41.4% during the first half of FY-83 [Ref. 20]. Additionally, while 44% represents an average, in the past the GEIR price, while always lower than the GINO price (which includes a 19.9% surcharge for FY-83), has occasionally exceeded the GSA Schedule price of a new instrument [Ref. 21].

D. GINO REQUIREMENTS DETERMINATION

GINO requirements consist of both new requirements and fleet shortages resulting from past, unfilled initial outfitting requirements. Program managers of new or updated weapons systems are responsible, as part of their ILS development, to identify GPETE requirements for the support of the system. The specific requirements are forwarded to the system command's GPETE Manager and funding requirements are passed to the program sponsor. Because of time constraints and other factors, not all GINO procurements however, follow this prescribed procedure. Some items are procured through other Navy activities (such as Naval Weapons Station, Seal Beach) with funding provided by the Ship Acquisition Manager (SHAPM). Others are procured through contractors or shipbuilders. [Ref. 22]

Generation of fleet GINO requirements is the responsibility of the type commanders/aircraft controlling custodians. While NAVMATINST 4790.25 states that this process should be accomplished through a review of the IMRL (Individual Material Readiness List), SPETERL (Ship's Portable Electronic/Electrical Test Equipment Requirements List), or STEAL (Shore Test Equipment Allowance List), this procedure is actually implemented in a number of ways. For example, COMNAVAIRLANT and COMNAVAIRPAC require fleet activities to report deficiencies using a "GINO card." COMSURFLANT requires the submission of an annual GPETE inventory by message and COMSUBLANT identifies deficiencies during the annual Weapons System Reviews.

Both the program manager and type commander generated GINO requirements are consolidated by the appropriate SYSCOM and submitted to NAVELEX 8151. NAVELEX 8151, in turn, reviews and consolidates these requirements and submits planned requirements to SPCC for procurement.

E. NON-STANDARD GPETE PROCUREMENT

Whenever the items listed in MIL-STD-1364 are not capable of meeting a required need and that need can be met by a non-standard item, a request/justification for non-standard GPETE is submitted in accordance with MIL-STD-1387, "Procedures for Submission of Application for Approval of Non-Standard General Purpose Electronic Test Equipment (GPETE)."

The request is submitted through the cognizant SYSCOM to NESEA Code 026 where review is accomplished by a contractor. The reviewer recommends approval or disapproval (a recommendation for disapproval is always preceded by discussion with the originator). NESEA Code 026 reviews the recommendation prior to forwarding the request to the originator with a copy to NAVELEX 8151. [Ref. 23]

If approved and funded, the non-standard GPETE requirement is consolidated with other GPETE requirements for procurement by SPCC or is purchased directly with authorization from NAVELEX 8151.

IV. IEEE-488 GENERAL PURPOSE INTERFACE BUS

A. BACKGROUND

1. Definition

The ANSI/IEEE-488-1978 is an American National Standard digital interface for programmable instrumentation. The standard specifies electrical, mechanical and functional characteristics for the purpose of:

1. defining a general purpose system for limited distance applications (twenty meters or less),
2. enabling the interconnection of independently manufactured instruments into a single functional system,
3. permitting instruments of a wide range of capability to be simultaneously interconnected into a system,
4. permitting direct communication between instruments,
5. defining a system with minimum restrictions on the performance characteristics of the instruments connected within the system,
6. defining a system that permits asynchronous communications over a wide range of data rates,
7. permitting the design of low cost systems composed of low cost instruments, and
8. defining a system that is easy to use. [Ref. 24]

Or simply, the standard provides a standard interface for instrument intercommunication, thereby permitting instruments to be easily integrated into an automated system.

2. History

Because of the increasing complexity of electronic equipment and a scarcity of electronics engineers and technicians during the past two decades, the electronics

industry found an increasing need to automate routine measurement tasks.

Early implementation of automated systems was both complicated and expensive. The lack of an interface standard resulted in each system being custom built. Interface designs were so individually tailored to a specific application, that even the addition of one instrument to a system could require major reengineering. As the result, these early systems were very expensive and automation was restricted to very high volume testing or to applications in which the system cost was low compared to the value of the test results.

During the late 1960s and early 1970s, the necessity of a industry standard interface became increasingly apparent and several electronic equipment manufacturers initiated research and development efforts in this area. Of these, Hewlett-Packard was the clear leader. International interest in the establishment of a suitable interface standard was also developing at this time, particularly among German electcnics organizations.

In mid-1972 Hewlett-Packard began participating with various national and international standards bodies in the development of an interface standard. The United States Advisory Committee, composed of both users and manufacturers, adapted the interface concept developed by Hewlett-Packard (called the Hewlett-Packard Interface Bus or HP-IB) as a starting point. The subsequent draft of an HP-IB based proposed standard was evaluated by the Committee and submitted to the International Electrotechnical Committee (IEC) in the fall of 1972 as the United State's proposal for an international interface standard.

In September 1974 the IEC approved the United States' proposal with minor modifications for formal ballot. The proposal was subsequently approved and published as IEC Standard 625 in 1977.

In the meanwhile, the IEEE Technical Committee on Automated Instrumentation approved a draft document of a HP-IB based interface standard in the fall of 1974. The IEEE Standards Board approved the draft in December 1974 and published it as IEEE Standard 488-1975 in April 1975. In October 1975 the same standard was approved by the American National Standards Institute (ANSI) and published as ANSI Standard MC1.1-1975. [Ref. 25]

The IEC and ANSI/IEEE standards are nearly identical and totally compatible with one exception-the connector. The IEEE standard (now generally referred to as the General Purpose Interface Bus, GPIB) employs a 24 self-wiping contact connector. The IEC standard specifies a 25 pin connector (using one additional ground) identical to the RS-232-C connector (therefore, presenting the possibility of equipment damage through the interconnection of these two incompatible buses). The interconnection of instruments implementing the two different connectors is easily accomplished using a IEC/IEEE adapter. [Ref. 24]

Since 1975 both the IEC and ANSI/IEEE standards have undergone a number of minor changes. The current standard is designated IEEE Standard 488-1978 and IEC Standard 625-1.

B. GPIB SPECIFICATIONS AND LIMITATIONS

1. GPIB Functional Subsets

The IEEE-Standard 488 specifies ten functions that a given instrument's interface may implement. All of these functions are optional. The extent to which a given function is implemented in an instrument is specified by functional subset designations (refer to Appendix C for a complete list of functions and subsets). Care is required in selecting GPIB configured instruments. "Many instruments are labeled "488 Compatible" or "GPIB Compatible," but in

the extreme the label may only mean that the instrument has a standard connector." [Ref. 26]

GPIB equipment selection is made even more difficult because of the general lack of information supplied by manufacturer's catalogs and, in many cases, even by the applicable maintenance manuals. The 1983 versions of the Hewlett-Packard, Tektronix and John Fluke catalogs generally do not specify the IEEE-488 functional subsets implemented in a particular instrument. At most, the manufacturer's catalogs may specify that an instrument is "talk only," "listen only," or "fully programmable." [Ref. 25,27,28]

Even the term "fully programable" can be deceptive. Although all functional subsets may be implemented in the "fully programmable" instrument, all the subsets may not be implemented for all of the front panel function and range controls. Thus, some front panel controls may be remotely operated (via the bus) while others require local (front panel) operation. [Ref. 29]

GPIB configured equipment selection is, therefore, not a straight forward process. It requires both a knowledge of the functional subsets required for a particular application and a determination of the functional subsets implemented by the instruments under consideration.

Navy interface requirements are specified by MIL-T-28800, paragraph 3.13.2. This specification states that all logic interfaces in electonic test equipment should be in accordance with IEEE-STD 488-1978 and goes on to specify the required functional subsets (refer to Appendix D). The United States Air Force Modular Automated Test Equipment (MATE) functional subset requirements are provided in Appendix E. Additional discussion of this topic takes place in Chapter 7.

2. Codes, Formats and Conventions

IEEE Standard 488 specifies the hardware interface, basic function protocol and a set of interface messages to control the interface functions. However, the standard does not specify the syntax or coding of device-dependent messages-the messages that control the programmable features of the instrument. [Ref. 30]

Therefore, while the hardware is specified, the language of communication is not. "It is much like a telephone system-the hardware link is well defined, but unless both parties speak the same language, communication is impossible." [Ref. 27]

In spite of the lack of code, syntax and convention standardization, many compatibility problems have been avoided by the adherence of most electronic equipment manufacturers to the following two related standards:

1. American Standard Code For Information Interchange (ASCII). ASCII is used in most GPIB instruments for bus data transmission.
2. ANSI X3.42. This standard format specifies three types of numbers (integers, reals, and reals with exponents) and transmission of the most significant digit first.

Adherence to these standards is required in the procurement of Navy electronic test equipment as specified in MIL-T-28800, paragraph 3.13.2.3:

> Unless otherwise required in the detailed specification, all numeric and alpha-numeric data (input and output) shall be American Standard Code for Information Interchange (ASCII) and the most significant digit shall be transferred first.

While two major potential sources of incompatibility have been eliminated by manufacturer adherence to related standards and by military specification, other sources of incompatibility have not yet been addressed. Some of these are:

1. Method of starting a message.
2. Method of terminating a message.
3. Convention to prevent execution of any part of a message until the entire message is received.

Some manufacturers have attempted to develop standards for these other sources of incompatibility. Tektronix's "Codes and Formats" standard represents one widely accepted approach [Ref. 31].

The Air Force's Proposed Standard 2806564 Rev D of 05 May 1982 delineates various syntax and coding requirements (Continuous Integrated Intermediate Language(CIIL)) for MATE qualified systems. CIIL has been submitted as IEEE Proposal 981 for inclusion in the IEEE-STD 488 [Ref. 32].

Pending addition of thorough codes, formats and conventions specification to the IEEE-STD 488, the selector of GPIB test equipment must ensure that procurement specifications require codes, syntax and conventions compatibility with the other GPIB instrumentation.

C. GPIB APPLICABILITY TO GPETE

Unlike the Air Force, which through its MATE program is attempting to make general purpose TMDE (i.e. GPETE) compatible to ATE applications, the Navy's ATE efforts are concentrated on development of a common ATE station for all applications. With a few exceptions, neither the current "family of ATE" (seven different ATE stations) or the Consolidated Systems Support (CSS) program (now entering full scale development) rely on the use of GPETE as ATE building blocks.

Therefore, the major application of GPIB in GPETE would be to facilitate automated calibration and, specifically, to facilitate the closed loop calibration of the instrument using the MECCA system.

The current number of GPETE items available with GPIB is small. A comparison of the MIL-STD-1364F and the 1983 versions of the Hewlett-Packard, John Fluke, Tektronix and Weinschel catalogs only identified one item with GPIB standard and seven others in which the GPIB option was available (refer to Appendix F). Although the number of items is currently small, it is increasing rapidly because of market demand and the simplicity of implementation resulting from the introduction of standard GPIB integrated circuits.

D. GPIB PROCUREMENT POLICIES

1. U.S. Air Force Policy

The United States Air Force purchases TMDE with IEEE-488 whenever it is available. This policy, which has been in effect since 1981, reflects verbal vice written direction and was implemented primarily to facilitate automated calibration. The Air Force has even been successful in securing agreements with manufacturers to provide GPIB in instruments when the option is not commercially available (e.g. Tektronix 465M oscilloscope). [Ref. 33]

2. U.S. Army Policy

The United States Army does not have a written policy for the procurement of IEEE-488 with its TMDE. In spite of some pressure from the Army's Development and Readiness Command (DARCOM) to devise such a policy, the individuals involved in TMDE procurement at the Communications and Electonics Command (CECOM) have avoided formulation of such a policy. These individuals prefer the

current situation because it permits a case-by-case evaluation and avoids the requirement to justify any policy deviations. The Army currently has few automatic test equipment (ATE) applications, but has introduced various automatic calibration systems. [Ref. 34]

3. Navy Policy

Currently the Navy does not have a specific GPETE GPIB procurement policy. To fully understand the current situation, the positions of each of the principals involved will be presented.

a. NAVELEX 8151 Position

NAVELEX 8151's position is summarized as follows:

1. No specific GPIB procurement policy currently exists. However, the formulation of such a policy is under study.
2. Ultimate responsibility for initiation of GPIB GPETE requirements rests with the users, i.e. the hardware systems commands.
3. Currently, requests for GPIB configuration of GPETE should be generated through normal MIL-STD-1387 (requests for non-standard GPETE) channels. However, generation of the specific policy should eliminate this requirement.
4. Receipt of MIL-STD-1387 requests for GPIB configured GPETE will result in a review of the MIL-STD-1364 characteristics to ascertain if GPIB should be made standard. [Ref. 35]

b. NAVELEX 8152 Position

NAVELEX 8152, as the TMDE manager for shore commands, holds the following position:

1. Any GPETE GPIB policy should be generated by NAVELEX 8151.
2. All GPETE should be procured with the bus when available. To make this point NAVELEX 8152 directed the NESEA contractor who consolidates shore establishment GPETE requirements to universally specify GPIB, where appropriate, on all future GPETE requirement lists. [Ref. 36]

c. NAVAIR 552 Position

Although NAVAIR 552 requires GPIB for most ATE applications, it has no specific policy regarding GPIB configuration of GPETE. Following the author's 22 February 1983 visit, NAVAIR 55223 tasked NAEC 92524 to coordinate with NAVSEA and NAVELEX in the formulation of such a policy. [Ref. 37]

d. NAVSEA 06C1C Position

The position of NAVSEA 06C1C regarding the GPETE GPIB procurement can be summarized as follows:

1. Prefers no definitive policy so that case-by-case decisions can be made.
2. Generally not enthusiastic about GPIB procurement because of the unlikelihood of GPETE ever being used in an automated test system. However, the special purpose application of GPETE as ATE building blocks is recognized.
3. The money spent on GPIB procurement can often better be utilized by procurement of other, more useful GPETE options. [Ref. 38]

V. GPETE GPIB COST-BENEFIT ANALYSIS

One of the contributing factors to the absence of a definitive GPIB GPETE procurement policy is the lack of an analysis which weighs relative costs, benefits, advantages and disadvantages of GPIB configured GPETE. This chapter will attempt to rectify that situation through the development of a simple cost-benefit analysis model for GPIB GPETE configuration.

The model attempts to quantify all GPIB costs and disadvantages and has succeeded in all but two relatively insignificant cases. On the other hand, the only cost advantage quantified is the resultant calibration manhour savings. All other advantages are presented as non-quantifiables.

Because of the greater degree of quantification achieved for costs and disadvantages compared to benefits and advantages and, because of the critical positions taken in derivation of the various cost elements, the model is a very critical analysis. This analysis is not, however, considered to be a "worst possible case" (a fortiori) analysis.

The model is based upon the life cycle cost of a single item of GPETE, not upon the entire instrument population. Its application, therefore, relies upon an assessment of the number of instruments expected to be procured.

Although quantifiable data was used where it was available, the scarcity of such data lead to a heavy reliance upon expert opinion. Because of its complexity and demands upon the experts' time, a Delphi technique was not used. Instead, various experts were surveyed via telephone conversations, questionnaires and visits. The results of these surveys and the model's parameters were then discussed and a

general concensus achieved during a presentation at the AC/D Conference in Dallas, Texas on 30 March 1983 (refer to Appendix G for a list of attendees). A discussion of the elements of the model follows.

A. CALIBRATION MANHOUR SAVINGS

Many claims have been made about the magnitude of the manhour reductions that can be achieved through automated calibration. Based upon comparisons made during an introductory tour of MECCA through a number of Navy calibration activities, MEC's promotional film "MECCA" claims that MECCA produces calibration manhour reductions [Ref. 39]. John Fluke Corporation claims that their 7405A Automatic Meter Calibration System (like MECCA based upon a FLUKE 1720A controller and 5102 meter calibrator) reduces manhours by "a factor of two to three" [Ref. 40]. Yet, in spite of these claims, discussions with numerous Navy calibration technicians indicate that MECCA open loop meter calibration is often slower than manual calibration.

The calibration techniques often used in the fleet provide the source of this disparity. Experienced technicians often by-pass some calibration steps and "piggy back" meters (calibrate more than one meter at a time), unauthorized methods not feasible with MECCA. MEC's primary reason for developing MECCA was not manhour savings, but rather improved procedural compliance. Based upon fleet comments MECCA is achieving this objective.

But the apparent failure of MECCA to reduce meter calibration manhours does not refute its potential. Fleet comparisons are of "apples and oranges"-complete versus incomplete procedures. Furthermore, these comparisons are based only upon open loop meter calibrations.

A survey of experts, limited quantified data and the AC/D Conference discussion resulted in agreement on a 30% manhour reduction factor for MECCA closed loop compared to MECCA open loop calibration (Appendix H provides a more detailed derivation).

This reduction is substantial, but not nearly what could be achieved if MECCA closed loop procedures were written to minimize operator intervention by only stopping the program to display test results for failures. MEC agreed with this assessment and plans to investigate changing the procedures accordingly [Ref. 41]. The impact of such a change was discussed at the AC/D Conference and a 50% reduction factor agreed to if the instrument calibration procedures (ICPs) are changed.

Even further reductions are possible in a high volume calibration facility. In this environment, with sufficient throughput and multiple MECCA stations, a single operator using minimum intervention ICPs could simultaneously carry out two or more calibrations.

B. INCREMENTAL COST ELEMENTS

1. Procurement Cost

The procurement cost is the incremental cost of inclusion of the IEEE-488 option in an item of GPETE. Although manufacturer's catalogs clearly specify this cost, the catalog cost represents a single unit retail price. Since the Navy purchases GPETE competitively and in quantity, its costs are far below retail.

In this life cycle cost model, the procurement cost is an output. The model will consider all other quantifiable costs and benefits and produce a figure that represents the maximum price that the Navy could pay for the GPIB option and still "break even" over the instrument's life

cycle. Comparison of this resultant cost to the known or anticipated incremental cost of the GPIB configuration will assist in the decision making process.

2. Incremental Life Cycle Software Costs

MECCA software consists of two different elements-the applications software (or "handler") and the instrument calibration procedure (ICP). The applications software is applicable to an entire class of test equipment. Currently MECCA application software is available or is under development for meter, enhanced meter, oscilloscope, signal generator and counter/frequency calibration. Because application software is not unique for a given instrument and would be developed regardless of any GPIB procurement decision, all related development, distribution and maintenance costs are "sunk" and non-incremental. Thus, application software costs are not considered in this analysis.

ICP software costs, on the other hand, may be either incremental or non-incremental. If the GPIB procurement decision results in the development of an additional ICP, the ICP software costs are incremental. Otherwise, ICP software costs are non-incremental and should not be considered. To aid in deciding if the ICP software costs should be considered in the cost-benefit model, a decision tree is provided in Appendix I.

There is a remote possibility that an applicable ICP already exists for the GPIB configured instrument, but no applicable ICP exists for the non-GPIB instrument. In such a case the incremental software costs become a credit for the procurement decision.

It is recognized that the decision maker will probably not have ready access to the information needed to make such a determination. However, MEC, as the control

center for all ICPs, should be able to provide the necessary information.

a. Software Development Costs

MEC is currently paying contractors $2,500 to develop a MECCA ICP (cost includes a paper conventional manual ICP) regardless of its simplicity or complexity [Ref. 42]. Each ICP may be applicable to as many as ten instruments, but because this analysis only considers cases in which development of a new ICP is required, all development costs will be apportioned to the first instrument. Software development costs will be "sunk" for future instruments that are able to use the ICP. Therefore, the software development cost per unit is calculated by dividing $2500 by the expected number of instruments to be procured.

b. Software Distribution Costs

MEC estimates that it costs $5 to produce and distribute a single ICP diskette (includes $2.80 for the blank diskette) [Ref. 43]. Although as many as ten ICPs can be placed on a given diskette, MEC is currently limiting this number to five (all meter ICP diskettes have five ICPs) [Ref. 44]. The initial issue quantity of the diskettes is one per site, but this analysis will assume that each site will requisition a second set of diskettes as a reserve. It is further assumed that each diskette will be replaced semi-annually as the result of ICP changes, damage and/or loss.

Distribution of ICP software for newly developed ICPs will, therefore, cost $4.00 (($5/disk X 2 disks/distribution x 2 distributions/year)/ (5 ICPs/disk)) per instrument model per site per year. Apportionment of the ICP distribution costs to the individual instruments is calculated by multiplying $4 by the number of MECCA sites

and dividing the result by the number of instruments to be procured.

c. Software Maintenance Costs

As the result of ICP errors, procedure updates and hardware changes, continued ICP software engineering is required after initial development. This cost element is very difficult to anticipate because some ICPs may never require change, while others are changed numerous times. A discussion of this subject at the 29-31 March 1983 AC/D Conference lead to a general concensus that the life cycle cost of ICP maintenance would at least equal the initial development cost ($2,500). To allocate this cost over the life cycle of the instrument, this analysis will assume that this cost will be $300 per year for each of the first 9 years of the instrument's life expectancy. Apportioning this cost to an individual instrument will again require division by the expected instrument population.

3. Incremental Life Cycle Repair Costs

Inclusion of the IEEE-488 bus in an item of GPETE introduces a degree of complexity to the instrument and is, therefore, likely to increase the instrument's life cycle repair costs. Calculation of life cycle repair costs involves the determination of two factors: the failure rate (reliability) and the average cost of a repair (maintainability).

a. GPIB Failure Rate

The Navy has experienced a GPIB rejection rate of approximately 30% during the acceptance testing of calibration standards [Ref. 45]. These rejections seldom represented GPIB malfunctions. Rather they almost universally represented non-standard GPIB implementation by the

manufacturer. Navy calibration standards GPIB acceptance tests are conducted using the Interface Technology ITC-488 bus tester and a Navy developed software (EPROM) program. In most cases of acceptance test failure, the manufacturer has willingly made the required modifications (usually only involving reprogramming of the instruments' GPIB EPROM software). Additionally, the occurance of such problems has been significantly reduced since the introduction of standard IEEE-488 integrated circuits. [Ref. 46]

After passing initial acceptance inspections, the IEEE-488 bus has proven to be extremely reliable. This analysis will use a 2% failure rate (a 2% chance of GPIB failure at each calibration induction). Derivation of this figure is provided in Appendix J.

b. Repair Manhours and Material Costs

For purposes of this analysis the average IEEE-488 repair action will require 3 manhours and $40 of materials. Because of the limited GPIB repair expertise currently in the fleet, the NARF LOE hourly rate of $48 will be used instead of the $28 FCA hourly rate. Derivation of the repair labor and material requirements is provided in Appendix K.

4. <u>Logistics Cost</u>

Introduction of an additional IEEE-488 instrument into the inventory will result in increased logistics costs because of the need for additional parts support, parts cataloging and holding costs. In the past IEEE-488 bus implementation was accomplished in a unique manner by virtually every manufacturer, often differing among instruments from the same manufacturer. Today implementation is becoming more standard, because of the introduction of the standard IEEE-488 integrated circuits (such as the Texas

Instrument's 9914A). Because of standardization, the incremental logistics costs of introducing another IEEE-488 configured instrument will not be significant. In this analysis, incremental logistics costs will be assumed to equal forty percent of the total life cycle repair material costs. Refer to Appendix M for the derivation of this figure.

5. Acceptance Testing Costs

Traditionally, GPETE product testing has consisted of bid sample testing and the subsequent acceptance of the manufacturer's test results. In spite of the high GPIB rejection rate during calibration standards acceptance testing, the traditional GPETE test methodology will suffice for GPIB configured GPETE.

As explained earlier, the high calibration standards GPIB rejection rate was the result of non-standard GPIB implementation, not GPIB malfunctions. Therefore, the objective of any GPIB GPETE testing program would be to ensure that the instrument conforms with the Navy's ITC-488 test parameters before contract award. In other words, the bid sample testing should include this GPIB test. Subsequent testing (and reporting) of sample items by the manufacturer using the ITC-488 would be made part of the contract.

The incremental cost of this additional test will be small and, since specified in the IFB (and contract), would be part of the incremental GPIB procurement cost. For these reasons, additional GPIB testing costs will not be considered as a separate element in this analysis.

C. OTHER COST-BENEFIT ANALYSIS PARAMETERS AND ASSUMPTIONS

1. FCA Cost Per Manhour

In this analysis an FCA hourly rate of $28 will be used. Derivation is provided in Appendix N.

2. Discount Rate

In accordance with DOD Directive 7041.3 and OMB Circular A-94, a ten percent (average factor) discount rate will be used in this analysis. An explanation of discounting and a table of discount factors is provided in Appendix C.

3. Instrument Life Expectancy

A generic list of instrument life expectancies is provided in Appendix P.

4. Salvage Value

This analysis will assume that the incremental salvage value a GPIB equipped test instrument is negligible.

5. Number of MECCA Sites

The number of MECCA sites is required to calculate software distribution costs. Because five ICPs reside on each diskette and as many as ten instruments may use the same ICP, it would be nearly impossible to calculate the exact number of MECCA sites to which a given diskette may be distributed. It will, therefore, be assumed that every diskette will be distributed to each MECCA site. The number of MECCA sites is equal the number of FLUKE 1720A and 1720A/AP custodians (93 as of 20 March 1983) [Ref. 47] and, therefore, can be obtained from The Weapons Quality Engineering Center (Code 373), Naval Weapons Station, Concord.

If current COMSURFLANT plans to place MECCA on virtually every combatant in the Atlantic Fleet are implemented, the number of sites will increase to approximately 250. Expansion of such a plan to the Pacific Fleet would further increase the number of MECCA sites to approximately 400.

6. Calibration Intervals

The length of the instrument's calibration interval is required to facilitate the calculation of the number and timing of calibrations (including a calibration prior to initial use) during the instrument's life cycle. Any one of the following means for this determination may be used:

1. Non-GPIB Parent Instrument in Inventory. In cases where a non-GPIB parent instrument already exists in the inventory, the calibration interval may be found in Section 3 of the "Metrology Requirements List (METRL)," NAVAIR 17-35MTL-1.
2. Non-GPIB Parent Instrument Not In The Inventory. In the case that a non-GPIB parent instrument does not exist in the inventory the following calibration cycles may be used:
   a) Manufacturer's Calibration Cycle. Manufacturer's calibration intervals tend to be shorter than the corresponding METRL calibration interval. A sample of twenty instruments (five from each MECCA applicable generic group) yielded a manufacturer's average interval of 7.8 months compared to the METRL average of 12.9 months (see Appendix Q for the sample elements). Therefore, use of the manufacturer's calibration interval may result in an unrealistically high calibration life cycle cost savings.

b) METRL Generic Calibration Cycle. Because the METRL generic calibration interval (found in Section 2) is a very conservative estimate, use of this figure will result in a unrealistically large number of life cycle calibrations and will, therefore, lead to an overly optimistic calibration manhour savings figure. Appendix Q provides a comparison of generic calibration intervals with both the METRL model number interval and the manufacturer's recommended interval.

Other more complex schemes are also possible. Many new instruments are initially placed on the generic calibration interval and subsequently changed as sufficient MEASURE data is accumulated (increasing 90% of the time) [Ref. 48]. A scheme using this approach would result in a gradually increasing calibration cycle.

7. Standard Calibration Manhours

This analysis will assume that the manhours required to perform a MECCA open loop calibration is equal to the standard manhour/calibration figures available from MEASURE. This assumption is tantamount to equating MECCA open loop and conventional manual manhour requirements. Based upon fleet input on the relative speed of MECCA open loop meter calibration, this assumption may be conservative.

Like the calibration interval, calibration standard manhours can be determined in several ways.

1. Non-GPIB Parent Instrument in Inventory. If the non-GPIB parent instrument exists in the inventory, the standard calibration manhours may be derived from any of a number of MEASURE report formats. The data used in the sample model execution (Appendix S) was taken from FRAMS format R-1.

2. Manufacturer's Standard. This rate can be derived by dividing the manufacturer's standard calibration fee by his current hourly rate (provided at the end of Appendix N). Caution, however, is advised in the use of this figure. Manufacturer service centers are generally better equipped and staffed than FCAs. Therefore, they generally complete calibrations in significantly less time than can be achieved in the fleet. A sample of 20 instruments (five from each MECCA applicable generic group) showed no discernible relationship between the manufacturer's and MEASURE manhours. In six cases the MEASURE standard was lower than the manufacturer's. In the other fourteen cases reverse was true. Overall, the MEASURE standards were slightly higher (3.5 hours compared to 3.1 hours) than the manufacturer standards. Refer to Appendix R for the sample data.

D. COST-BENEFIT ANALYSIS MODEL EXECUTION

Once all the input parameters, cost elements and benefits are chosen, calculated or determined, they are assigned to the appropriate year(s) in the instrument's life cycle. Discounting of the yearly totals (see Appendix O for an explanation of discounting) and totaling the resultant present discounted values (PDV) yields the "break even" procurement cost. An example of this process is provided in Appendix S.

E. SENSITIVITY ANALYSIS

Using the example provided in Appendix S, Appendix T examines the model's sensitivity (degree of output response) to variation of a number of individual input parameters. The model was found sensitive to the following parameters:

1. Procurement Quantity
2. FCA Cost Per Manhour
3. Calibration Manhour Savings Factor
4. Standard Calibration Manhours
5. Calibration Interval
6. GPIB Failure Rate

The model was relatively insensitive to the following parameters:

1. All Software Cost Parameters (for large procurement quantities).
2. Number of MECCA Sites
3. Manhours Per Repair Action
4. Material Costs For Repair
5. Logistics Cost Factor

F. NON-QUANTIFIABLE ADVANTAGES AND DISADVANTAGES

1. Disadavantages

a. Non-Availability Due to IEEE-488 Malfunction

It is possible that an IEEE-488 interface bus failure could result in decreased test equipment availability. However, the probability of such an occurance is remote for the following reasons:

1. The IEEE-488 bus is extremely reliable as indicated by the 2% incidence of failure.
2. The probability of a bus failure "hanging up" the entire instrument is very small. In virtually every case the failure of the bus will not affect local operation. See Appendix U.
3. Because the bus is only used for calibration, bus failure would not preclude conventional manual or MECCA open loop calibration. Thus, except in the case of a GPIB induced "hang up," an urgently

required instrument could be calibrated and returned to the user and bus repairs accomplished at a convenient future date.

b. Absence of Local Functional Checking

Using a MECCA closed loop calibration procedure, all ranges and functions are set remotely (via the interface bus) and all data is collected/transferred remotely. It is, therefore, possible that the instrument may be functioning satisfactorily during remote operations while problems exist in local (front panel) operation. An example of this problem would be a front panel digital display malfunction that goes undetected because of the remote data transfer. Therefore, it is possible that a locally malfunctioning instrument could be returned to the user certified as calibrated.

Unless such a malfunction occurred after induction for calibration, it would usually be detected by the user and be reported to the calibration activity at induction. In the remote possibility that such a malfunction occurred after induction, it is entirely possible that it could escape detection.

A possible solution is robotic calibration. This technique would involve the use of a robot to perform an automated calibration using the front panel controls. Such a technique has been proposed by various individuals at the Naval Avionics Center, but as of yet no research and development funding has been made available. [Ref. 49]

2. <u>Advantages</u>

a. Calibration Procedure Standardization

The primary justification for the development of the MECCA system was to ensure that calibrations were being accomplished in a consistent manner throughout the fleet. Prior to MECCA, calibration relied upon the technician's individual skill and methodology. Although manual calibration procedures provide a detailed, step-by-step method, some technicians tend to disregard the procedures as they become more experienced and develop unauthorized shortcuts that are, unfortunately, often taught to less experienced technicians.

MECCA, even in its open loop mode, has improved procedural compliance by forcing the technician to step through the procedure and ensuring the calibrator is properly set for each parametric check. However, the MECCA open loop method still relies upon the technician to properly make calibrator/TI adjustments. In the closed loop mode the controller makes direct TI readings and comparisons, thus reducing the technician's role and the chance for human error. The closed loop method, therefore, ensures a higher degree of calibration procedural standardization than afforded by MECCA open loop calibration.

b. Improved Calibration Accuracy

Erroneous calibration procedures may induce inaccuracies into the test equipment. These inaccuracies are subsequently passed along to the GPETE supported electronic systems. By improving calibration procedural compliance, MECCA closed loop calibration improves system maintenance, accuracy and reliability.

c. Better Utilization of Experienced Technicians

Because the controller ensures proper calibrator outputs and TI indication readings and comparisons as well as providing the operator with a simple stepwise procedure, the level of experience and training required to calibrate using an open loop technique is less than that required for either conventional calibration or MECCA open loop techniques. Thus, a lower skill level technician can be used for calibration while the highly trained and experienced technicians are utilized where they are most needed, doing equipment repair.

The primary commercial justification for calibration automation is based upon this advantage and the resultant reduction in calibration technician salaries.

d. Test Equipment Availability Improvement

By speeding calibration procedures, closed loop MECCA calibration will reduce the calibration turnaround time and the significant backlogs experienced by most Navy calibration facilities. A reduction in turnaround time will also permit a reduction in "pipeline" test equipment assets, thus reducing GPETE inventory and procurement requirements.

e. Multi-Component Applications and Calibration

While this analysis has been limited to those items of GPETE that would use GPIB only for calibration purposes, more and more test systems are being developed that rely upon the system components working as a unit through bus interface communication. GPIB configured GPETE can be used and calibrated as part of such a system.

f. More Thorough Calibrations

Because of the speed at which test point readings and data transfer can be achieved via GPIB, it is practical to test a larger number of parameters. Thus, significantly more thorough calibrations can be accomplished in as little or less time than is possible with non-GPIB instruments.

g. Diagnostics

The interface bus can not only be used to ascertain instrument accuracy, but can also be used to diagnose circuitry malfunctions. Development of such diagnostics is part of the AC/D program and research and development work is underway at the NARF Pensacola's Type II calibration laboratory.

Introduction of such a diagnostic system would reduce troubleshooting manhours, reduce technical skill level requirements, and improve fault isolation accuracy. Additionally, such a system could be configured to integrate via the interface bus with the supply data base to rapidly ascertain the availability of the required replacement part(s).

h. Intermittent Fault Isolation

Technicians are often confronted with diagnosing an intermittent fault. Because a fault cannot be corrected until it is isolated, intermittent faults result in a great deal of time and effort, not to mention technician frustration.

The ability of closed loop calibration procedures to run in a continuous loop (programmed only to stop when a discrepancy is located) permits the test instrument to run continuously (over night or over a weekend) until the fault surfaces and is recorded.

i. FCA Capability Enhancement

The reduced skill level requirements and increased calibration speed and thoroughness possible with closed loop calibration could make the FCAs capable of performing calibrations that were previously only within the capability of a NARF or shipyard. The resulting migration of calibration capability will not only decrease turnaround time, but will also result in NARF and shipyard NIF savings.

j. State-Of-The-Art Procurement

Specification of IEEE-488 interface bus in the GPETE salient procurement characteristics may result in the procurement of a higher quality instrument through:

1. Elimination from competition of marginal instruments and manufacturers that are unable to support GPIB.
2. Elimination of the price disadvantage of instruments that provide GPIB as standard.

k. Miscellaneous Advantages

The ability of the IEEE-488 bus to transfer data directly would permit the instrument to be interfaced with other computerized data collection and monitoring systems. Examples of such systems are a MEASURE card printer and a computerized quality assurance (QA) monitoring system.

G. CONCLUSIONS

While the author has not attempted to quantify the two GPIB disadvantages and numerous advantages, it is obvious that the later far outweigh the former. Assessment of the values of these factors is strictly subjective and will, therefore, be left to the discretion of the decision maker. However, because a GPIB instrument may have a longer useful life stemming from its ability to take advantage of future

developments, the author would not consider a $100 assessment to be unreasonable.

The execution of the model (Appendix S) and sensitivity analysis (Appendix T) provides the decision maker with the following general guidance: a positive GPIB procurement decision is likely when:

1. anticipated procurement quantities are large (at least 100),
2. the ICP is long and complex, and/or
3. the calibration interval is short (one year or less).

VI. RELATED ISSUES

So far this thesis has addressed current calibration workload reduction and productivity enhancement initiatives and has added one additional consideration--test equipment configuration. This chapter addresses other relevant issues.

A. GPETE STANDARDIZATION

NAVELEX's current approach to GPETE "proliferation minimization" only addresses part of the issue. While the current approach successfully minimizes small quantity and non-standard GPETE procurement, it fails to address the proliferation caused by formally advertised GPETE follow-on procurement.

The current DOD environment exerts a great deal of pressure to formally advertise procurements. Unfortunately, formal advertising is not always cost effective. It only considers one cost element, the procurement cost, and ignores all other life cycle cost (total cost of ownership) considerations. In the GPETE arena this pressure has lead to formally advertising for units required to supplement the population of an instrument currently in the inventory. As a result, the fleet is often supporting two or more different instruments procured to fill the same requirements and based upon identical salient characteristics. A recent example is provided by the AN/USM-425 oscilloscope contract awarded to Kikisui (Japan) in December 1982.

The Navy and the Air Force issued a IFB for AN/USM-425 oscilloscopes to supplement the current inventory of Tektronix 465M, Option 49 (AN/USM-425) oscilloscopes.

Tektronix's bid of $1,550 per unit for the 465M was $191 higher than Kikisui's $1,359 bid, so Kikisui was awarded the contract. In spite of NAVMAT direction to ensure "total cost effectiveness" in GPETE procurement [Ref. 12], no consideration was given to the incremental logistics costs (spare parts provisioning, training, ICP development, etc.) that would be associated with the introduction of an oscilloscope different from the one already in the inventory. If considered, these incremental logistics costs may have offset the $191 price difference.

This example, unfortunately, is not an isolated case. In spite of the increased emphasis on logistics and life cycle costs, formally advertised procurement continues to take precedence.

B. GPETE INTEGRATED LOGISTICS SUPPORT

While formal advertising continues to overshadow logistics considerations, the current state of GPETE ILS does not lend itself to involvement in the acquisition process.

Within NAVELEX 8152 GPETE ILS functions are performed by a single individual assisted by five contractor personnel. To date GPETE ILS efforts have concentrated on the post-acquisition development of operational logistics support plans. Little effort has been given to pre-acquisition considerations such as the development of life cycle cost and cost-benefit analyses.

While a full scale logistics support analysis (LSA) effort (MIL-STD-1388) could not be justified for off-the-shelf (OTS) commercial test equipment (CTE) procurement, some pre-acquisition ILS effort would be beneficial. Comparisons of the relative calibration intervals, maintainability factors, ease of operation, training requirements, and provisioning would be valuable in differentiating

between instruments under consideration. While intentions have been expressed to move in this direction, the presence of the necessary commitment and expertise within NAVELEX 815 is debatable.

C. TRAINING

Formal calibration technical training is available from two sources. A sixteen week course taught at Lowry Air Force Base (Denver) qualifies graduates as Electronics Standards Specialists (NEC 1588). A six week NALC Detachment course (taught in Norfolk and San Diego) trains Field Calibration Technicians (NEC 6673). Both courses are general and theoretical. Little "hands on" training is provided.

Fleet units, therefore, must rely almost totally on OJT for practical calibration training. While OJT can often be arranged at a local NARF, shore based AIMD, or Naval Shipyard, the availability of additional sources of training would be most beneficial.

Development of the following additional training sources is recommended:

1. On-Site Factory Schools

Fleet units have found the use of factory schools impractical because of the tuition expense ($1000-2000), the TAD expense (most manufacturer's facilities are not convenient to government quarters), and their infrequent availability (1 or 2 classes per year).

However, some electronic equipment manufacturers, such as Tektronix, are willing to teach their courses at Navy installations if sufficient students are available [Ref. 50]. If type commanders worked in concert, a sufficient number of qualified, interested students could easily

be assembled. This approach would eliminate most TAD funding requirements, reduce the fleet unit's administrative workload, and foster fleet participation, particularly if tuition was paid directly by the type commanders.

2. Phase Package Training

Another approach is the establishment of phase package training at the NALC Detachments and/or the Naval Aviation Maintenance Training Detachments (NAMTD). Such training would compliment the Lowry and NALC Detachment theoretical training by providing "hands on" training in specific calibration phase packages. A similiar program tailored to the surface Navy's needs could also be established.

3. Sound/Slide and Video Cassette Training

Many test equipment manufacturers make available sound/slide and video cassette training on the operation, calibration and repair of specific instruments. Additional presentations are available from other sources. For example, NATC Patuxent River has a ten lesson University of Colorado video cassette course on IEEE-488.

Where such programs/presentations are available, they should be made a logistics element and purchased as part of the ETE procurement package. For instruments already in the fleet the type commanders should seek out and review appropriate programs/presentations and make them (and the necessary projectors and VCRs) available to the fleet.

4. Manufacturer Periodicals

Some electronic instrument manufacturers publish periodicals (Hewlett-Packard's is called "Bench Briefs") containing articles on test equipment calibration and repair techniques. Type commanders should investigate the

availability of these publications and arrange distribution to fleet units ("Bench Briefs" are free).

D. ACS COORDINATION

Although MEC is coordinating ACS ICP development for the fleet through MECCA and NALC is coordinating ACS ICP development through AC/D, these two programs are not coordinated with one another. This lack of coordination has lead to redundant efforts and disputes. The following illustrates:

1. Both MEC and AC/D (NATC) have developed "multi-handlers" (applications software applicable to multiple component ACSs).
2. MEC has developed a MECCA program generator. The NALC program is tasked with developing a universal program generator.
3. In several cases, NARF Quality Assurance Divisions have refused to certify MECCA ICPs due to alleged procedural discrepancies.

For the Navy to take full advantage of its various ACS development efforts, overall coordination is necessary. This function is and should be MEC's responsibility. However, since MEC is sponsored and funded by each of the hardware systems commands, it lacks the power to exert authority over their independent ACS initiatives.

Through the mutual cooperation of each of the systems commands, real authority for ACS coordination should be vested in MEC. For its part, MEC should establish an independent division tasked with the following responsibilities:

1. Coordination of all ACS development efforts
2. Development and maintenance of a universal program generator that will be used in the development of <u>all</u> Navy ACS ICPs.
3. Certification of <u>all</u> Navy ACS ICPs.

This division should be sufficiently independent to permit the unbiased evaluation and coordination of both MEC and non-MEC generated ACSs and ACS ICPs.

VII. RECOMMENDATIONS

The following is a brief summary of the author's recommendations.

A. IEEE-488 SUBSET REQUIREMENTS

The current Navy IEEE-488 subset requirements (Appendix D) are inadequate to facilitate automated calibration. A revised list, based upon expert opinion, is presented in Appendix V (Appendix W compares the current Navy, USAF MATE and the recommended subsets).

These subset requirements should be presented to the industry as Navy GPIB requirements. It is anticipated that the electronics industry will respond favorably to such requirements based upon the following:

1. The positive reception USAF requirements (including configuration control) for MATE qualification received from industry.
2. The relative ease of implementing <u>all</u> functional subsets when GPIB is implemented using a standard IEEE-488 integrated circuit.

B. IEEE-488 CODE, SYNTAX AND CONVENTION STANDARDS

The Navy should convene a study group to investigate the various codes, syntax and convention standardization proposals now before the IEEE Standards Board. The results of their efforts should be used to guide Navy GPIB procurement and to facilitate Navy support of the most appropriate proposal (or, if necessary, to generate a new proposal).

C. GPETE GPIB PROCUREMENT POLICY.

A GPETE GPIB procurement policy should be established. Such a policy need not be a universal "buy" or "don't buy" directive. It should, however, provide a uniform means for weighing the individual costs and benefits associated with each procurement.

Additionally, any GPIB policy should ensure inclusion of all required IEEE-488 functional subsets and conformance with the codes, syntax and conventions required for compatibility with other instruments in the inventory.

D. GPETE FOLLOW-ON PROCUREMENT

Steps should be taken to reduce GPETE proliferation caused by the formal advertising of follow-on procurements. Initial procurement of GPETE requirements (based upon entirely new requirement of improved salient characteristics) should be procured competitively. But the merits of standardization suggest a different approach is required for follow-on procurement. The following methods should be considered:

1. <u>Multiple Year Options</u>. Instead of the current practice restricting GPETE procurement contracts to one year with a single year option, contracts with two or more option years should be sought. This method would reduce the frequency of letting contracts while retaining the option to change to another instrument model as the state-of-the-art dictates.
2. <u>Multiple Year Contracts</u>. The U.S. Army is currently using five year contracts for TMDE procurement [Ref. 51]. This approach not only reduces formally advertised follow-on procurements, but will probably result in a lower procurement price relative to the multiple year option approach because of reduced

uncertainty for the manufacturer. However, this approach could also lock in the procurement of GPETE that subsequently becomes obsolete or proves unreliable. Therefore, this approach should not be used in the following cases:

a) GPETE approaching the end of its life cycle.

b) GPETE at the beginning of its life cycle that has not yet proven its reliability.

3. Use of Life Cycle Costs. Life cycle costs, not procurement costs, could be used as the cost criteria for follow-on procurement. Such an approach may be viable for competitive negotiation, but would be very difficult to implement for a formally advertised procurement.

4. Use of Logistics Costs. A cost element that can be considered along with procurement cost in a formally advertised procurement is the logistics cost. An IFB could require the bid to include quantification of logistics elements such as publications, training, provisioning and ICP development. This approach would give the incumbent a legitimate price advantage while retaining most of the advantages of formal advertising.

5. Use of DAR Standardization Exception. A determination and findings (DNF) could be initiated to justify a negotiated sole source follow-on procurement of GPETE. Justification for the DNF is found in the Defense Acquisition Regulation (DAR) exception for standardization of technical equipment deployed outside the United States or aboard ship [Ref. 52].

E. ACS COORDINATION

It is recommended that a division of MEC be established to coordinate ACS development, develop and maintain a universal program generator, and certify ACS ICPs.

F. CALIBRATION/REPAIR TRAINING

To improve fleet calibration/repair test equipment training, the following actions are recommended:

1. Arrange factory training at major Navy installations.
2. Establish NALC Detachment/NAMTD phase package training courses.
3. Make test equipment repair/calibration sound/slide and video cassette training courses available to the fleet.
4. Make manufacturer test equipment instruction/information periodicals available to fleet units.

VIII. EPILOGUE

As the result of the attention that the research for this thesis brought to the GPETE/GBIP question, the following actions have been initiated;

1. MEC is giving active consideration to modification of MECCA closed loop procedures to limit operator intervention to parametric check failures [Ref. 41].
2. NAVELEX 8151 has initiated consideration of a GPETE GPIB policy [Ref. 35].
3. NAVAIR 55223 has directed NAEC 92524 to coordinate with NAVSEA 06C1C and NAVELEX 8152 in formulating a GPETE GPIB policy [Ref. 37].
4. NAVELEX 8152 has directed that, where applicable, future shore command GPETE requirements include GPIB [Ref. 36].
5. The NAVMAT TMDE Action Group (chaired by NAVELEX 08T2) will make GPETE GPIB policy an agenda item for the group's meeting in Norfolk, Virginia on 18-19 May 1983 [Ref. 53].

APPENDIX A
DEFINITIONS

AC/D	Automatic Calibration and Diagnostics
ACS	Automated Calibration System
ACL/SCD	Automatic Calibration Laboratory/Satellite Calibration Development
AFB	Air Force Base
AIMD	Aircraft Intermediate Maintenance Department
AIMSO	Aircraft Intermediate Maintenance Support Office (Patuxent River, MD)
ANSI	American National Standard Institute
AOP	Average Over Period
APN	Aircraft Procurement, Navy
ASCII	American Standard Code For Information Interchange
ATE	Automatic Test Equipment
BA	Budget Activity
BB	Building Block
CATIIID	Computerized Automatic Tester, Digital
CECOM	Communications and Electronics Command (U.S. Army)
CIIL	Continuous Integrated Intermediate Language
COMNAVAIRLANT	Commander, Naval Air Force, U.S. Atlantic Fleet
COMNAVAIRPAC	Commander, Naval Air Force, U.S. Pacific Fleet

COMSUBLANT	Commander, Submarine Force, U.S. Atlantic Fleet
COMSURFLANT	Commander, Surface Force, U.S. Atlantic Fleet
CPI	Consumer Price Index
CRT	Cathode Ray Tube
CSS	Consolidated Systems Support
CSS	Contractor Support Services
CTE	Commercial Test Equipment
CV	Aircraft Carrier
CY	Calendar Year
DAR	Defense Acquisition Regulations
DARCOM	Development and Readiness Command (U.S. Army)
DMM	Digital Multimeter
DLA	Defense Logistics Agency
DNF	Determination and Findings
DOD	Department of Defense
EOP	End of Period
EPROM	Erasable Programmable Read Only Memory
ETE	Electronic Test Equipment
FCA	Fleet Calibration Activity
FMSO	Fleet Material Support Office
FRAMS	Flat Rate Measurement System
FY	Fiscal Year
GEIR	GPETE End Item Replacement
GINO	GPETE Initial Issue
GPETE	General Purpose Electronic Test Equipment
GPIB	General Purpose Interface Bus
GSA	General Services Administration
GSE	Ground Support Equipment
GSI	GPETE Support Item

H-P	Hewlett-Packard, Co.
HP-IB	Hewlett-Packard Interface Bus
ICP	Instrument Calibration Procedure
ICP	Inventory Control Point
ID	Interface Device
IEC	International Electrotechnical Committee
IEEE	Institute of Electrical and Electronic Engineers
IFB	Invitation For Bids
I/JSATP	Industry/Joint Service Automatic Testing Project
ILS	Integrated Logistics Support
IMRL	Individual Material Readiness List
LCC	Life Cycle Costs
LEM	Logistics Element Manager
LOE	Level Of Effort
LSA	Logistics Support Analysis
MACL	Mobile Automated Calibration Laboratory
MACS	Mobile Automated Calibration System
MATE	Modular Automatic Test Equipment
MEASURE	Metrology Automated System for Uniform Recall and Reporting
MEC	Metrology Engineering Center
MECCA	Modularly Equipped and Configured Calibrators and Analyzers
METRL	Metrology Requirements List
MIL-HDBK	Military Handbook
MILPERS	Military Personnel
MIL-STD	Military Standard
MPN	Military Personnel, Navy
MTBF	Mean Time Between Failure
NAEC	Naval Air Engineering Center

NALC	Naval Aviation Logistics Command
NAMTD	Naval Aviation Maintenance Training Detachment
NARF	Naval Air Rework Facility
NAS	Naval Air Station
NATC	Naval Air Test Center
NAVAIR	Naval Air Systems Command
NAVCOMPT	Navy Office of the Comptroller
NAVELEX	Naval Electronics Systems Command
NAVMAT	Naval Material Command
NAVSEA	Naval Sea Systems Command
NAVSUP	Naval Supply Systems Command
NCL	Navy Calibration Laboratory
NEC	Navy Enlisted Classification Code
NESEA	Naval Electronic Systems Engineering Activity (St. Inigoes, MD)
NIF	Navy Industrial Fund
NPS	Naval Postgraduate School
NSF	Navy Stock Fund
NWS	Naval Weapons Station
OJT	On-The-Job Training
OMB	Office of Management and the Budget
O&MN	Operations and Maintenance, Navy
OPN	Other Procurement, Navy
OTS	Off-the-Shelf
PDV	Present Discounted Value
PHONECON	Telephone Conversation
PME	Precision Measuring Equipment
POM	Program Objective Memorandum
QA	Quality Assurance
RADCOM	Radar and Communications Tester
SAI	Science Applications, Inc.

S&E	Supply and Equipage
SHAPM	Ship's Acquisition Manager
SM&R	Source, Maintenance and Recoverability
SOA	State-of-the-Art
SPCC	Ship's Parts Control Center
SPETE	Special Purpose Electronic Test Equipment
SPETERL	Ship's Portable Electronic/Electrical Test Equipment Requirements List
STEAL	Shore Test Equipment Allowance List
SYSCOM	Systems Command
TAMS	Test and Measuring Systems Office (NAVELEX Code 08T)
TEK	Tektronix, Inc.
TI	Test Instrument
TIMS	Transmission Impairment Measurement System
TMDE	Test, Measuring and Diagnositic Equipment
USAF	United States Air Force
VCR	Video Cassette Recorder
WPN	Weapons Procurement, Navy

APPENDIX B

ELECTRONIC TEST EQUIPMENT CLASSIFICATIONS

Navy electronic test equipment (ETE) is classified by the Naval Material Command Electronic Test Equipment Classification Board. The board consists of one representative from NAVAIR, NAVSEA and NAVELEX and is chaired by NAVELEX (an individual other than the NAVELEX representative) and meets as required to classify ETE into one of the following three catagories:

1. General Purpose Electronic Test Equipment (GPETE). GPETE is that electronic test equipment that is capable of, without modification, or generating, modifying or measuring a range of parameters of electronic functions required to test two or more equipments or systems of basically different design. Newly designed and manufactured commercial off-the-shelf (OTS) electronic test equipment (CTE) used to support one system, will normally be classified as GPETE if it is reasonable to predict its use will be required with more than one equipment or system.
2. Special Purpose Electronic Test Equipment (SPETE). Electronic test equipment that is specifically designed to generate, modify, or measure a range of parameters of electronic functions of a specific or peculiar nature required to test a single system or equipment, and it is reasonable to predict its use with more than one system is unlikely.
3. Other-ETE. Any test equipment not considered as either GPETE or SPETE. [Ref. 54]

APPENDIX C

IEEE-488 FUNCTIONAL SUBSETS

The following tables [Ref. 55] represent each of the IEEE-488 standard's functions, except the controller function (which is not applicable to GPETE). The degree to which a given function is implemented in an instrument is represented by a functional subset designation. For example, in the "Remote-Local" function, RL0 means that the function is not implemented; RL1 means that both the "basic remote-local" and "local lock out" subsets are implemented; while RL2 means that only the "basic remote-local" subset is implemented.

SOURCE HANDSHAKE		SH0	SH1
Full Capability	Allows the device to generate the handshake cycle for transmitting data		X
No Capability		X	
ACCEPTOR HANDSHAKE		**AH0**	**AH1**
Full Capability	Allows a device to generate the handshake for receiving data		X
No Capability		X	
DEVICE TRIGGER		**DT0**	**DT1**
Full Capability	Allows an instrument or group of instruments to be triggered or some action started upon receipt of the group executive trigger (get) message		X
No Capability			

TALKER (EXTENDED TALKER)*		T0 TE0	T1 TE1	T2 TE2	T3 TE3	T4 TE4	T5 TE5	T6 TE6	T7 TE7	T8 TE8
Basic Talker (Basic Extended Talker)	Allows an instrument to transmit data		X	X	X	X	X	X	X	X
Talk Only Mode	Allows an instrument to transmit data without a controller on the bus		X		X		X		X	
Unaddressed If My Listen Address (MLA)	Prevents an instrument from being a talker and a listener at the same time						X	X	X	X
Serial Poll	Allows an instrument to send a status byte in response to a serial poll		X	X			X	X		
No Capability		X								

LISTENER (EXTENDED LISTENER)*		L0 LE0	L1 LE1	L2 LE2	L3 LE3	L4 LE4
Basic Listener (Basic Extended Listener)	Allows an instrument to receive data		X	X	X	X
Listen Only Mode	Allows an instrument to receive data with a controller on the bus		X		X	
Unaddressed If My Talk Address (MTA)	Prevents an instrument from being a talker and a listener at the same time				X	X
No Capability		X				

SERVICE REQUEST		SR0	SR1	
Full Capability	Allows an instrument to request service from the controller with the SRQ line		X	
No capability		X		
REMOTE-LOCAL		**RL0**	**RL1**	**RL2**
Basic Remote-Local	Allows the instrument to switch between manual (local) control and programmable (remote) operation		X	X
Local Lock-Out	Allows the return to local function to be disabled		X	
No Capability		X		
PARALLEL POLL		**PP0**	**PP1**	**PP2**
Basic Parallel Poll	Allows an instrument to report a single status bit to the controller on one of the data lines (D107-D108)		X	X
Remote Configuration	Allows the instrument to be configured for parallel poll by the controller		X	
No Capability		X		
DEVICE CLEAR		**DC0**	**DC1**	**DC2**
Basic Device Clear	Allows all instruments on the to be initialized to a pre-defined cleared state		X	X
Selective Device Clear	Allows individual instruments to be cleared selectively		X	
No Capability		X		

APPENDIX D

NAVY IEEE-488 FUNCTIONAL SUBSET REQUIREMENTS

The following Navy IEEE-488 functional subset requirements are specified in MIL-STD-28800C, "General Specification For Test Equipment For Use With Electrical and Electronic Equipment," paragraph 3.13.2.2:

Interface Function	Symbol	Subset Requirements
Source Handshake	SH	SH1 required
Acceptor Handshake	AH	AH1 required
Talker	T	T1 required
Listener	L	L1 required
Service Request	SR	SR1 required
Remote Local	RL	RL1 required
Parallel Poll	PP	not mentioned
Device Clear	DC	not mentioned
Device Trigger	DT	not mentioned

APPENDIX E
MATE IEEE-488 SUBSET REQUIREMENTS

The following are the minimum allowable IEEE-488 function subset requirements for USAF Modular Automatic Test Equipment (MATE) qualified instruments:

Interface Function	Symbol	Subset Requirements
Source Handshake	SH	SH0 not allowed
Acceptor Handshake	AH	AH0 not allowed
Talker or Extended Talker	T or TE	T0 not allowed TE0 not allowed T1,T2,T5,T6 preferred TE1,TE2,TE5,TE6 preferred
Listener or Extended Listener	L or LE	L0 not allowed LE0 not allowed
Service Request	SR	SR1 optional
Remote Local	RL	RL0 not allowed RL1 preferred RL2 not preferred
Parallel Poll	PP	PP1, PP2 optional
Device Clear	DC	optional
Device Trigger	DT	optional
Controller*	C	C0 not allowed C1,2,3,4,5 preferred

* Not applicable to GPETE type instruments which will never serve in the controller function.

Source: Proposed MATE System Control Interface Standard, Proposed Standard No: 2806564 Rev. D, FSCM 13604, 05 MAY 82.

APPENDIX F

GPIB GPETE AVAILABILITY

The following is a list of those standard and substitute GPETE items the author was able to identify as being available with GPIB either as a standard feature or as an option [Ref. 25,28,56].

Mfr	Model Nr	Description	Mfr Option Info Opt Nr	Cost	Note
FLUKE	8600A-01	4.5 Digit DMM	529	250	1
FLUKE	8800A/AA	5.5 Digit DMM	529	250	1
FLUKE	1953A	Counter	15	500	
H-P	5328A	Counter	011	450	2
H-P	8620C	Sweep Generator	011	950	
H-P	8660C	RF Signal Generator	005	250	3
H-P	5340A	Counter	011	425	
H-P	3586C	Voltmeter	Standard Feature		
WEINSCHEL	9675-200	Sweep Generator	08	675	

NOTES:

1. Unit must be used in conjunction with a Fluke 1120A IEEE-488 Translator.
2. Unit is currently being bought as GPETE with the GPIB option installed.
3. The GPIB option is "listen only."

APPENDIX G

AC/D CONFERENCE ATTENDEES

The following individuals attended the AC/D conference in Dallas, Texas, 29-31 March 1983.

Name	Activity	Code
Don Tobey	SAI, Dallas	N/A
Richard Anderson	NALC Det West	3022
John D. Crellin	NALC Patuxent River	3321
Walt Fitzgerald	NALC Patuxent River	3322
Vernon Marsh	NALC Det East	3012B3
Elton E. Artis	NARF Norfolk, Type II	66010
Rick Renfro	NARF Alameda, Type II	66200
Emmett Parker	NARF Alameda, Type III	66300
Wayne Porter	NALC Det West	SAI/NORIS
Joseph A. Walker	NARF Pensacola, Type III	94700
Mike Foley	NARF Pensacola, Type II	66400
Robert Slocomb	NARF Cherry Point	94207
Doity Gaskill	NARF Cherry Point	9420
V. (Pete) Grier	NARF Cherry Point	52120
Gene Allerton	DALFI, Inc., San Diego	N/A
Barry Sanderson	NARF Jacksonville	94461
Frank Brooks	NARF Jacksonville	94400
Ken Moon	NARF Jacksonville	94461
Jim Lopez	NARF North Island	94320
Terry T. Krogel	NARF North Island	94325
Edward R. Greer	NATC Patuxent River	TS-243
Paul Willenborg	NATC Patuxent River	TS-243
LCDR W.D. Stahler	Naval Postgraduate School	SMC 1689
Thomas Leedy	National Bureau of Standards	N/A
Les Scott	Cerberonics Corp., San Diego	N/A
H. E. Bradley	Naval Avionics Center	430
H. T. Riebe	Naval Avionics Center	432

Peter Sargent	DALFI Corp., Oakland	N/A
Elwin Speary	SAI, Patuxent River	N/A
G.R. Flintrop	SAI, NCL Tustin	N/A

APPENDIX H

LIFE CYCLE CALIBRATION SAVINGS ANALYSIS

At the author's request MEC conducted a comparative analysis of the time required to conduct an open and closed loop MECCA calibration. The test instrument used was the FLUKE 8860A digital multimeter, the only instrument for which both an open and closed loop ICP had been developed. The test involved three technicians calibrating the instrument using both techniques. Although the exact test figures are not available for release, the test showed an approximate 50% reduction in the closed loop mode.

A survey was also conducted via phone conversations and questionnaires to ascertain the estimates of individuals involved in automatic calibration system development and familiar with MECCA. The following estimates were obtained:

Name/Activity/Reference	Estimate
Mr. Mark Anderton COMNAVAIRLANT 532B11 phonecon of 29 Nov 1983	10-25%
Mr. Robert Cole MEC Pomona visit of 07 Jan 1983	25% or more
Mr. Robert Holcomb SAI NCL Tustin phonecon of 13 Jan 1983	90%
Mr. Micheal Eagar NWS Crane Questionnaire	20%
Mr. Micheal Foley NARF Pensacola Type II Lab Questionnaire	25-30%

Mr. Paul Willenborg 25%

NATC Patuxent River

Questionnaire

Mr. Richard Renfro 10%

NARF Alameda Type II Lab

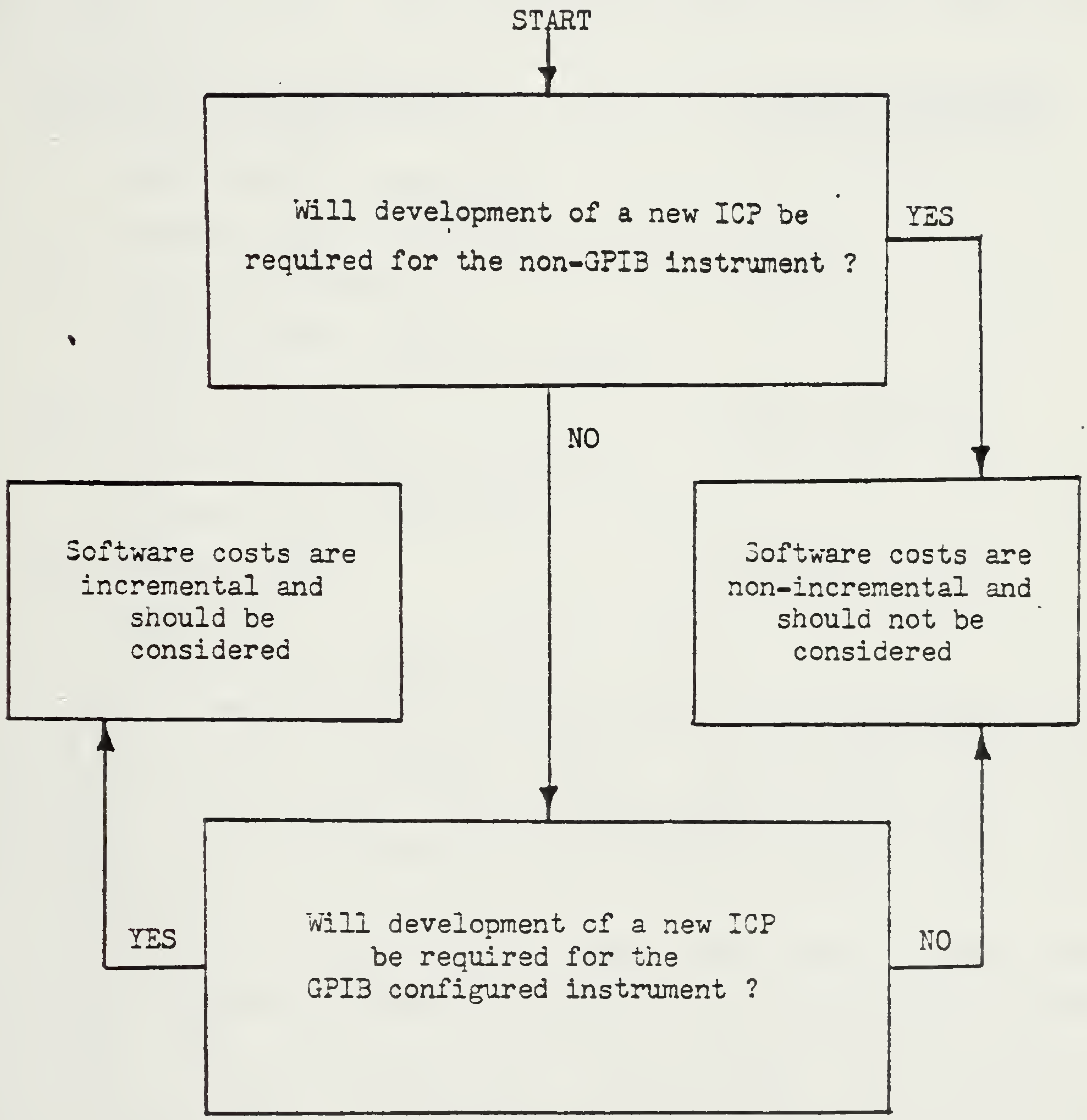
Questionnaire

These results were presented at the AC/D Conference in Dallas, Texas on 30 March 1983 (refer to Appendix G for a list of attendees) and the following manhour reduction factors were agreed upon:

1. Conservative Estimate (current MECCA closed loop procedures): 25%
2. Best Estimate (current MECCA closed loop procedures): 30%
3. Best Estimate (revised MECCA closed loop procedures): 50%

APPENDIX I
SOFTWARE COST DECISION TREE

The following decision tree is designed to assist the decison maker in determining if software development, maintenance and distribution costs are incremental to a GPIB procurement decision.



APPENDIX J
FAILURE RATE DERIVATION

The repair incidence (failure rate) was derived through a survey of various individuals highly experienced in the operation and maintenance of IEEE-488 configured test equipment. The survey was conducted through phone conversations and questionnaires. The following is a complete listing of the responses:

Name/Activity/Reference	Failure Incidence
Mr. James Cigler NARF Norfolk Type III phonecon of 23 Nov 83	Approximately 5%
Mr. Paul Willenborg NATC Patuxent River Questionnaire dtd 24 Feb 83	1-2 %
Mr. Donald Marshall NAS Whidby Island Type III phonecon of 12 Jan 83	Less than 5%
Mr. Micheal Eagar NWS Crane phonecon of 17 Jan 83	Maximum of 5%

These survey results were presented and discussed at the AC/D Conference in Dallas, Texas, on 30 March 1983 (see Appendix G for a list of the conference attendees). The concensus of the conference was that 2% failure rate should be utilized.

Although the 2% failure rate may appear quite low, further analysis indicates otherwise. If one only considers the GPIB duty cycle as that time during which the bus is used (i.e. the condition of the bus does not deteriorate during idle time), the 2% failure rate translates to a mean

time between failure (MTBF) of only 94.5 hours ((.7 X 2.7 hrs/calibration)/(.02 failures/calibration)) for the example used in Appendix S.

This MTBF is significantly lower than that calculated by test equipment manufacturers during warranty report preparation. Two examples are offered.

1. Hewlett-Packard's warranty report on the 8672 signal generator estimates the IEEE-488 bus (HP-IB) failure rate at .2% per year (based upon 2000 hours per year). This translates to a MTBF of 1,000,000 hours, four orders of magnitude greater than the rate used in this analysis. Additionally, H-P calculated that the HP-IB only contributed .9% to the overall failure rate of the instrument. This failure rate, however, is based on an instrument not connected to another instrument or controller. It, therefore, does not include the failure rate of the GPIB connector. [Ref. 57]
2. Tektronix has calculated the failure rate of a GPIB cable (with two connectors) as .0324 per 1000 hours. This translates to a MTBF of nearly 31,000 hours. [Ref. 58]

Because of these low failure rates, the incremental fee that manufacturers charge for inclusion of GPIB option coverage in their annual repair agreements is very small (most often zero). Examples are provided in Appendix L.

APPENDIX K

IEEE-488 REPAIR MANHOURS AND MATERIAL COSTS

The average cost of an IEEE-488 repair in terms of manhours and materials was established through interviews with and the completion of questionnaires by various individuals experienced with bus repair. The following is a sample of the responses:

Name/Activity/Reference	Manhours	Material Cost
Mr. James Cigler NARF Norfolk Type II phonecon of 23 Nov 83	2	$ 20-25
Mr. Paul Willenborg NATC Patuxent River Questionnaire dtd 24 Feb 83	2	$ 25
Mr. Donald Marshall NAS Whidby Island Type II phonecon of 12 Jan 83	2	$ 25
Mr. Craig Gaby Hewlett-Packard Service Center, Atlanta phonecon of 18 Jan 1983	2 (if bus controlled by separate microprocessor) 6 (if bus and instrument controlled by a single microprocessor)	

The results of this survey were discussed at the AC/D Conference in Dallas, Texas on 30 March 1983 (for a list of attendees see Appendix G). The discussion resulted in an estimate of 3 manhours and $40 of material for an average repair action. The primary justification given for these relatively low averages was that a high percentage of GPIB repairs only involve reseating a circuit card.

Further justification for these low average expenditures comes from the following:

1. The incremental charge for inclusion of the GPIB option in a manufacturer's annual repair agreement is small, most often zero (see Appendix L for examples). Since electronics firms are in business to make money, it can be assumed that the GPIB is not only reliable, but is also relatively inexpensive to repair.
2. The parts involved in GPIB implementation are generally inexpensive. The following examples [Ref. 59,60] illustrate:

Texas Inst. 9914A GPIB Integrated Circuit	$16.00
SN160 Buffer	5.00
SN162 Buffer	6.50
HP-IB Internal Cable (H-P 5328A Counter)	16.50
HP-IB Circuit Card (H-P 5328A Counter)	206.00

APPENDIX L

GPIB REPAIR CONTRACT COSTS

The following data reflects the annual repair agreement rates for Tektronix and Hewlett-Packard test equipment available with GPIB as an option [Ref. 61,62].

			Cost of Annual Repair Contract		
Mfr	Model	Nomenclature	Non-GPIB	With GPIB	Delta
H-P	6002A	Power Supply	75	75	0
H-P	6129C	Voltage Source	230	230	0
H-P	6130C	Voltage Source	260	260	0
H-P	6131C	Voltage Source	260	260	0
H-P	8016A	Word Generator	360	360	0
H-P	8018A	Data Generator	360	360	0
H-P	8620C	Sweep Generator	75	95	20
H-P	8660A	Signal Generator	265	265	0
H-P	436A	Power Meter	60	60	0
H-P	1610B	Logic Analyzer	110	110	0
H-P	1615A	Logic Analyzer	85	85	0
H-P	1640B	Data Analyzer	105	105	0
H-P	2804A	Thermometer	160	160	0
H-P	1980B	Waveform Storage	100	115	15
H-P	3771A/B	Data Analyzer	280	280	0
H-P	4262A	LCR Meter	125	170	45
H-P	4943A	TIMS	310	310	0
H-P	4944A	TIMS	310	310	0
H-P	5328A	Counter	30	30	0
H-P	5340A	Counter	370	370	0
H-P	5342A	Counter	170	200	30
H-P	5345A	Counter	245	245	0
H-P	3964A	Tape Recorder	260	260	0
H-P	3968A	Tape Recorder	575	575	0
H-P	5150	Printer	105	105	0

TEK	468	Oscilloscope	430	430	0
TEK	5223	Oscilloscope	305	305	0
TEK	492	Spectrum Anal	610	630	20

APPENDIX M

LOGISTICS COST FACTOR DERIVATION

A logistic cost/material cost ratio was one of the most illusive elements in this analysis. Consultation with members of the Naval Postgraduate School (NPS) financial management facility and phone conversations with NAVSUP, NAVCOMPT and the Fleet Material Support Office (FMSO) failed to locate a viable figure.

With the assistance of CDR Peter W. Blondin, NPS financial management faculty, the following ratio of budget elements related to logistics system operation costs and the cost of materials processed by the system was devised:

1. Logistics System Operating Costs (Numerator). The estimated cost of operating the Navy logistics system was based upon the following FY-83 budget authorizations:

Appropriation	Areas Included	Approx Amt
O&M,N (BA-7)	NAVSUP Hdqtrs.	$ 60 M
	ICPs/FMSO	200 M
	Stock Points	220 M
	Transportation	460 M
O&M,N (Other BAs)	Stock Points	100 M
O&M, DOD	ICPs/Stock Points	400 M
MPN	MILPERS in Supply	300 M
Procurement	Investment Costs	100 M
TOTAL APPROXIMATE FY-83 COSTS		$ 1,840 M

2. Supply System Material Costs (Denominator). This figure consists of FY-83 budget authority for spare parts and for Navy Stock Fund (NSF) material.

Appropriation	Areas Included	Approx Amt
OPN	Spares Procurement	$ 81 M
WPN	Spares Procurement	127 M

APN	Spares Procurement	1,988 M
NSF (O&M,N)	Spares Procurement	3,000 M
Other Stock Funds	Spares Procurement	800 M
O&M,N (BA-7)	Eng/Component Rework	1,034 M
TOTAL APPROXIMATE FY-83 Costs		7,030 M

3. Logistics Cost/Material Cost Ratio. Division of the logistics costs ($1,840 M) by the total material costs ($7,030 M) yields .2617 (26.17%).

This 26% figure grossly understates (perhaps by as much as 100%) the actual cost ratio because of the absence of several major logistics system cost elements which were not available. Among these absent cost elements are the following:

1. Costs of Afloat Supply Support. The Navy employs numerous supply support ships to deliver supplies to the operating units. The above logistics system cost estimates do not include any costs for their operation.
2. Costs of Logistics Planning. A good portion of the Naval Material Command and its associated systems commands (other than NAVSUP) are directly involved in the planning and programming of logistics support within the Navy. This involvement includes both the acquisition of major systems and the logistical support of these systems. Since it was not possible to segregate individual costs of supply support from other major logistical areas, no cost for the Naval Material Command or its systems command (other than NAVSUP) have been included.

If a true ratio could be calculated it would lie somewhere between 25% and 55% [Ref. 63]. In this analysis the mid-point of this range, 40%, will be used for the logistics cost factor. Fortunately, as demonstrated in the sensitivity analysis (Appendix T) the accuracy of this factor is

not critical to the analysis. In fact, the difference in the model's output using 25% factor as compared to a 55% factor is only $1.10.

APPENDIX N

FCA MANHOUR COST CALCULATION

The cost of a FCA manhour is based upon the NAVCOMPT Manual's "Statistical Costing of Military Personnel Services" [Ref. 64] and an overhead rate equal to that recorded by the Navy Industrial Funded (NIF) Naval Air Rework Facilities (NARFs) during FY-82.

1. Hourly Labor Costs. The hourly labor cost is based upon the average hourly rates for paygrades E-4 and E-5 as taken from the "Navy Composite Standard Military Rate Table" [Ref. 65].

Paygrade	Hourly Rate
E-4	7.66
E-5	9.07
Average	8.36

This average figure is adjusted for the following two factors:

Retirement Entitlement Accrual:	26.5%
Other Personnel Support Cost Accrual:	23.0%

NOTE: The Other Personnel Support Costs includes a portion of quarters, subsistence, medical and commissary costs not included in the standard rate.

Application of these factors yields:

Current Costs	
Standard Rate	8.36
Other Personnel Support	1.92
Total Current Costs	10.21
Deferred Costs	
Retirement	2.22
Total Labor Cost	12.50

2. Overhead Rate. The overhead application of NIF funded activities during FY-82 was calculated from the Department of the Navy, Office of Comptroller, "Navy Industrial Fund" Report for the period ending 30 September 1982. The following figures are taken from the NARF section of that report:

Direct Labor	$ 372,083,000
Overhead Labor	337,557,000
Overhead Materials & Services	255,511,000

The overhead rate was calculated by dividing total overhead by direct labor, yielding 1.59.

3. Hourly Overhead Cost. To avoid charging overhead against a deferred labor cost (retirement), the overhead rate is applied only to the current hourly labor cost (standard rate and other personnel support costs). Therefore, the hourly overhead charge equals the current hourly labor cost ($10.28) multiplied by the overhead rate (1.59) = $16.35.

4. Total Hourly Cost Of FCA Manhour. The hourly FCA cost equals the total hourly labor cost ($12.50) plus the hourly overhead cost ($16.35) = $28.85. This figure is rounded down to $28 per hour for use in the cost-benefit model.

It is recognized that many substantive arguments can be made against the derivation of this figure. It could be argued that application of an overhead charge is invalid for a shipboard FCA because the facility cost would remain unchanged even if a man was eliminated. It might also be argued that the overhead charge is actually too low considering the size of the Navy support establishment and the relatively forward position of the FCA in that structure. Similar legitimate assaults could be made on practically every factor in this derivation. However, no other figure exists and this figure is not out of line with the related hourly rates discussed in the following paragraphs.

AIMSO is conducting an "AIMD Cost Collection Program" and has developed two AIMD manhour cost estimates. The preliminary results for FY-81 (the figures for FY-82 and FY-83 are still under development) list salary/benefits costs of $13 per hour and a total hourly cost (including materials) of $40 per hour [Ref. 66]. Adjusting these figures by application of the miliary pay raises for FY-82 and FY-83 (14.7 and 4.0 percent respectively) to the salary/benefit portion and application of the consumer price index (CPI) for CY-81 and CY-82 (8.9% and 3.9% respectively) to the material portion, yields a FY-83 salary/benefit rate of $15.51 per hour and a FY-83 total cost rate of $45.26 per hour. The disparity between these figures and those developed for this analysis can be explained in two ways. First, the AIMSO study considers all AIMD personnel including officers and chief petty officers, whereas this study only considers PO3s and PO2s. Secondly, the cost of materials in a FCA are, on the average, lower than that of most AIMD work centers for the following reasons:

1. FCA inductions are primarily scheduled maintenance and, therefore, often only require minor adjustments. Most other AIMD inductions are unscheduled repairs and, therefore, require part replacement a higher percentage of the time.
2. The repair parts used in the FCA generally consist of relatively inexpensive electronic components. Many of the repairs in other AIMD work centers require replacement of more complex and expensive components.

The $28/hour figure compares to the following hourly rates charged by other calibration and repair activities:

NARF (average FY-83 NIF LOE)	$ 48.00
John Fluke Corporation	57.50

Tektronix	60.00
Hewlett-Packard	65.00

APPENDIX O

DISCOUNTING AND THE DISCOUNT FACTOR TABLE

Discounting is a technique used to adjust future cash flows to their current value (present discounted value (PDV)). "The present value of $1 payable next year is $1/(1+r). This is the amount which, if invested today at an annual interest rate r, will yield $1 in one year." [Ref. 67] Therefore, the further an expected cash flow is into the future, the less its value will be in current terms. The discount factor (provided below) is the decimal fraction used to reduce future cash flows to their present value (PDV).

In accordance with DOD Directive 7041.3 and OMB Circular A-94, a ten percent discount rate will be utilized in this analysis. The discount rates used will be "average" factors vice "end of the year" factors for the following reasons:

> The rationale for using average factors instead of end-of-the-year factors is essentially twofold:
>
> 1. After the initial investment cost, most of the annual costs and benefits associated with a project do not occur at a single point in time but rather are spread throughout the year. This is typically true of operating costs and salaries. Such costs are best approximated by an annual lump payment occurring in the middle of the year.
>
> 2. The exact time of occurrence of costs and benefits in out years of an economic life may not be known with certainty. In the absence of more specific information, there is no reason to assume that these costs and benefits will occur only on the anniversaries of acquisition; they might occur at any point in the year. Average factors are generally applied to such costs. Errors on the low side should occur about as often as errors on the high side. In the long run, there will be an offsetting effect. [Ref. 68]

Year	Average Factor
0	1.000
1	0.954
2	0.867
3	0.778
4	0.717
5	0.652
6	0.592
7	0.538
8	0.489
9	0.445
10	0.405
11	0.368
12	0.334

APPENDIX F
GPETE LIFE EXPECTANCY

The life expectancy of various generic classes of GPETE was derived through the presentation of an input given to the author by Mr. Earl Hampel, COMNAVAIRLANT Code 532B1, and its subsequent revision at the AC/D Conference in Dallas, Texas on 30 March 1983 (refer to Appendix G for a list of attendees).

	Life Expectancy Estimates	
Instrument Type	Hampel Input	AC/D Revision
Counters	20 years	12 years
Oscillcscopes	8-10 years	9 years
Signal Generators	7 years	10 years
Digital Meters	10-15 years	10 years

In this analysis, the AC/D revised life expectancies will be used.

APPENDIX Q

CALIBRATION INTERVAL COMPARISON

The following is a comparison of the METRL model number, METRL generic and the manufacturer's recommended calibration interval for a sample of twenty instruments (five from each MECCA applicable generic group) [Ref. 69,70,71].

			Calib Interval (Months)		
Mfr	Model Nr	Nomenclature	Generic	METRL	Mfr
H-P	970A	Digital Multimeter	6	12	12
H-P	3465A	Digital Multimeter	6	12	12
H-P	3469B	Digital Multimeter	6	10	12
H-P	3476B	Digital Multimeter	6	10	12
H-P	3490A	Digital Multimeter	6	6	3
H-P	5328A	Counter	6	24	12
H-P	5340A	Counter	6	38	6
H-P	5345A	Counter	6	20	6
H-P	5360A	Counter	6	9	3
H-P	5382A	Counter	6	12	12
H-P	8616A	Signal Generator	6	16	6
H-P	8614A	Signal Generator	6	13	6
H-P	8660B	Signal Generator	6	12	6
H-P	8672A	Signal Generator	6	6	6
H-P	8660B	Signal Generator	6	12	6
H-P	618C	Signal Generator	6	16	6
TEK	465M	Oscilloscope	6	16	12
H-P	1703A	Oscilloscope	6	5	6
H-P	1707B	Oscilloscope	6	5	6
H-P	180C	Oscilloscope	6	12	6
H-P	1201B	Oscilloscope	6	4	6
	AVERAGE		6.0	12.9	7.8

APPENDIX B
STANDARD MANHOUR COMPARISON

The following is a comparison of the standard calibration manhours between manufacturers' service centers and Navy activities. Twenty instruments are listed, five from each of the generic groups for which MECCA ICPs have or will be developed. Navy data is based upon five year MEASURE data from the FRAMS Report R-1 of 19 JAN 1983. Manufacturer figures are based upon the current standard calibration cost [Ref. 62,70] divided by the current hourly calibration/repair cost for the particular manufacturer ($65/hour for Hewlett-Packard, $60/hour for Tektronix).

			Calib Std Manhours	
Mfr	Model Nr	Nomenclature	FRAM R-1	MFR
H-P	970A	Digital Multimeter	2.1	1.0
H-P	3465A	Digital Multimeter	2.4	2.3
H-P	3469B	Digital Multimeter	2.4	3.0
H-P	3476B	Digital Multimeter	1.8	1.0
H-P	3490A	Digital Multimeter	2.2	3.5
H-P	5328A	Counter	2.1	4.0
H-P	5340A	Counter	2.3	4.2
H-P	5345A	Counter	4.1	4.0
H-P	5360A	Counter	4.2	6.0
H-P	5382A	Counter	2.3	1.5
TEK	465M	Oscilloscope	3.2	2.0
H-P	1703A	Oscilloscope	3.3	4.0
H-P	1707B	Oscilloscope	6.7	4.0
H-P	180C	Oscilloscope	2.0	1.5
H-P	1201B	Oscilloscope	2.6	2.5
H-P	8616A	Signal Generator	3.3	2.5
H-P	8614A	Signal Generator	3.6	2.5
H-P	8660B	Signal Generator	4.6	4.5

H-P	8672A	Signal Generator	12.0	6.0
H-P	618C	Signal Generator	3.4	2.5
		AVERAGE	3.5	3.1

APPENDIX S
COST-BENEFIT MODEL SAMPLE EXECUTION

The following example execution of the cost-benefit analysis model developed in chapter 5 is based upon a December 1982 Navy procurement of 3000 AN/USM-425 oscilloscopes from Kikisui (Japan). The derivation of each parameter and the applicable calculations will first be presented. The results will then be assigned to the appropriate life cycle year, discounted and totaled.

1. Procurement Quantity. 3000 units (per the contract).
2. Instrument Life Cycle. 9 years for an oscilloscope (Appendix P).
3. Calibration Cycle. The 16 month calibration interval of the current AN/USM-425 oscilloscope (the Tektronix 465M, option 49) will be used in this analysis. Taking into account the initial calibration (assumed to take place at time zero) a total of seven life cycle calibrations will be scheduled for execution during the following months: 0, 16, 32, 48, 64, 80 and 96.
4. Standard Calibration Manhours. 2.7 manhours, the standard calibration manhours of the Tektronix 465M (from FRAMS format R-1), will be used.
5. Software Costs. For the sake of illustration, software costs will be included in this calculation.
   a) Software Development Costs. The $2,500 ICP development cost divided by 3000 units yields a cost of $0.83 per unit (assigned to time 0).
   b) Software Maintenance Costs. $300 per year software maintenance cost divided by 3000 units yields a cost of $0.10 per year for each of the first

nine years of the instrument's projected life (the entire life of an oscilloscope).

c) <u>Software Distribution Costs</u>. $4 per MECCA site multiplied by 100 MECCA sites (rounded up from the current 93 sites) and divided by 3000 units yields a cost of $0.13 per unit for each year of its life cycle.

6. <u>Repair and Logistics Costs</u>. A typical GPIB repair consumes 3 NARF manhours ($144), $40 of materials and a logistics cost of $16 (.4 X $40) for a total cost of $200. Over this instrument's life cycle the chance of a failure is 14% based upon a 2% chance of failure upon induction for each of the seven required calibrations. Fourteen percent of $200 is $28.00. This repair cost is charged at the life cycle's mid-point, the fifth year.

7. <u>Calibration Savings</u>. The savings resulting from closed loop calibration is 30% of the standard manhours (2.7) multiplied by the FCA manhour cost rate ($28). This calculation yields a $22.68 savings to be applied at time zero and years 2, 3, 4, 6, 7, and 8.

These costs/savings are applied to the appropriate life cycle years, discounted to obtain a present discounted value (PDV) (for an explanation of discounting refer to Appendix C), and totaled as follows:

YR	DISCOUNT FACTOR	COST ELEMENT	COST	TOTAL	PDV
0	1.000	Software Develop	(0.83)		
		Calib Savings	22.68		
		Total		21.85	21.85
1	0.954	Software Maint	(0.10)		
		Software Dist	(0.13)		
		Total		(0.23)	(0.22)
2	0.867	Software Maint	(0.10)		

		Software Dist	(0.13)		
		Calib Savings	22.68		
		Total		22.45	19.46
3	0.778	Software Maint	(0.10)		
		Software Dist	(0.13)		
		Calib Savings	22.68		
		Total		22.45	17.47
4	0.717	Software Maint	(0.10)		
		Software Dist	(0.13)		
		Calib Savings	22.68		
		Total		22.45	16.10
5	0.652	Software Maint	(0.10)		
		Software Dist	(0.13)		
		Repair/Logistics	(28.00)		
		Total		(28.23)	(18.41)
6	0.592	Software Maint	(0.10)		
		Software Dist	(0.13)		
		Calib Savings	22.68		
		Total		22.45	13.29
7	0.538	Software Maint	(0.10)		
		Software Dist	(0.13)		
		Calib Savings	22.68		
		Total		22.45	12.08
8	0.489	Software Maint	(0.10)		
		Software Dist	(0.13)		
		Calib Savings	22.68		
		Total		22.45	10.98
9	0.445	Software Maint	(0.10)		
		Software Dist	(0.13)		
		Total		(0.23)	(0.10)
TOTAL					92.94

If the anticipated incremental cost of GPIB configuration is less than $92.94, inclusion of GPIB configuration will result in a life cycle cost benefit. If the

anticipated GPIB cost exceeds $92.94, the decision maker must determine if the non-quantifiables are worth the additional life cycle cost.

APPENDIX T

SENSITIVITY ANALYSIS

This sensitivity analysis evaluates the effect on the model output attributable to variation of the input parameters. The Kikisui oscilloscope procurement data used in the model execution example in Appendix S will be used throughout this analysis.

Because the model output is the maximum price that could be paid for GPIB configuration without increasing life cycle costs, the "break even point" (zero dollars) output is the point at which GPIB would have to be free in order for there to be no life cycle cost disadvantage.

1. Procurement Quantity. Because the fixed software costs are amortized over the procurement quantity, the model is sensitive to quantity variations at the lower procurement levels.

Procurement Quantity	Model Output
3000	$ 92.94
1000	87.53
500	80.11
250	65.26
100	20.73
78	0.00

2. Calibration Manhour Reduction Factor. Because calibration manhours savings is the only quantified benefit in the model, any variation of its elements has a significant impact on the model's output.

Reduction Factor	Model Output
50%	$ 167.57
30%	92.94
25%	73.43
20%	54.60

10%	16.95
5.5%	0.00

3. Standard Calibration Manhours. Like the calibration manhour reduction factor, standard calibration manhours directly impacts the only quantified benefit. Therefore, the model output is sensitive to its variation. Unlike the calibration manhour reduction factor, this input element can usually be determined with relative certainty because of the existence of the MEASURE data.

Standard Manhours	Model Output
0.50	$ 0.00
1.00	20.37
2.00	61.46
2.70	92.94
3.00	102.54
4.00	139.63
5.00	184.71

4. FCA Manhour Cost. Because the only cost savings factor is directly proportional to the FCA manhour cost, the model is very sensitive to its variance.

FCA Manhour Cost	Model Output
$ 40	140.67
35	120.50
30	100.33
28	92.94
25	80.16
20	59.98
15	39.81
10	19.64
5.13	0.00

5. Calibration Interval. As was the case with standard calibration manhours, the calibration interval can usually be obtained from existing data. Like

previous parameters that directly affected calibration savings, the model is sensitive to variation in calibration interval.

Calib Interval	Nr Calib	Model Output
6 months	18	$265.49
12 months	9	128.69
16 months	7	92.94
24 months	5	62.41
36 months	3	33.04
48 months	3	29.32
60 months	2	16.76

6. Repair and Logistics Costs. Repair and logistics costs may be varied by changes to the failure rate, average repair time, material costs, and/or logistics costs. These elements are considered separately.

a) Failure Rate. Because failure rate affects overall repair costs, the model is more sensitive to its variance than it is to variance of the individual repair cost elements.

Failure Rate	Model Output
0.5%	$ 106.64
1%	102.07
2%	92.94
5%	65.56
12.2%	0.00

b) Repair Time. Repair time would have to increase significantly to have a great impact on the model's output.

Repair Time	Model Output
1 MHR	$ 101.71
2 MHRS	97.33
3 MHRS	92.94
5 MHRS	84.19
10 MHRS	62.29
24.2 MHRS	0.00

c) Material Costs. Like repair time, material costs would have to vary substantially to have any significant impact on the model output.

Material Cost	Model Output
$ 40	$ 94.22
80	87.82
200	72.46
500	34.06
766	0.00

d) Logistics Cost Factor. Variation of the logistics cost factor has very little effect on the models output.

Logistic Factor	Model Output
2586.0	0.00
2.00	87.10
1.00	90.75
0.55	92.39
0.40	92.94
0.25	93.49

7. Number of MECCA Sites. The number of MECCA sites only affects software distribution costs and, therefore, the model is very insensitive to its variation.

MECCA Sites	Model Output
100	$ 92.94
250	91.54
400	90.03
10,012	0.00

8. Software Costs. For large quantity procurements, such as the Kikisui AN/USM-425 contract, the model is extremely insensitive to software cost variations.

a) Software Development Costs. The $2,500 ICP development cost is as firm as any used in this analysis. However, even if it were doubled to $5,000 it would only reduce the model's output by $ 0.83.

b) Software Maintenance Costs. Doubling the annual ICP maintenance cost to $600 per year would only decrease the model's output by $ 0.70.

c) Software Distribution Costs. Doubling the annual ICP distribution costs to $800 per year would only decrease the model's output by $ 0.94.

APPENDIX U

AVAILABILITY REDUCTIONS DUE TO IEEE-488 INSTALLATION

This study only considers use of the IEEE-488 interface bus for calibration purposes, therefore, only bus failures that impact calibration accomplishment will adversely affect instrument availability. Because a functional interface bus is not required for the test instrument's functional use, the instrument could be calibrated using bus independent (MECCA open loop or conventional manual) methods and returned for use. Therefore, the only bus failure that would preclude any form of calibration would be one which would cause instrument inoperability in both the local and remote modes (a "hang up").

To ascertain the probability of such a "hang up" a number of individuals experienced in IEEE-488 bus operation and maintenance were surveyed. The results of this survey follows:

Name/Activity/Reference	"Hang Up" Probability
Mr. Richard Calhoun MEC Pomona Phonecon of 29 Nov 1983	Definite possibility
Mr. Micheal Foley NARF Pensacola Type II Phonecon of 21 Jan 83	"Highly Improbable"
Mr. Paul Willenborg NATC Patuxent River Visit of 24 Feb 83	Has heard of one such incidence
Mr. Robert Mawson John Fluke Corp. Phonecon of 29 Nov 1982	Does not believe that it is possible.

Mr. Robert Holcomb SAI NCL Tustin phonecon of 13 Jan 1983	"Highly improbable"
Mr. Craig Gaby Hewlett-Packard Service Center, Atlanta phonecon of 18 Jan 1983	Bus failure very seldom affects local operation.

The findings of this survey were presented to the AC/D Conference in Dallas, Texas on 30 March 1983 (see Appendix G for a list of attendees). The consensus opinion of the conference attendees was that the possibility of such a malfunction is remote.

APPENDIX V

IEEE-488 SUBSET REQUIREMENTS FOR AUTOMATED CALIBRATION

The following IEEE-488 automated calibration subset requirements represent the identical inputs of Mr. Edward Greer, Naval Air Test Center Code TS-243, and Mr. Richard Calhoun, Metrology Engineering Center:

Interface Function	Symbol	Subset Requirements
Source Handshake	SH	SH0 not allowed
Acceptor Handshake	AH	AH0 not allowed
Talker or Extended Talker	T or TE	T0,T3,T4,T7,T8 not allowed TE0,TE3,TE4,TE7,TE8 not allowed T1,T2,T5,T6 preferred TE1,TE2,TE5,TE6 preferred
Listener or Extended Listener	L or LE	L0 not allowed LE0 not allowed
Service Request	SR	SR1 required
Remote Local	RL	RL0 not allowed RL1 preferred RL2 not preferred
Parallel Poll	PP	PP1, PP2 optional
Device Clear	DC	DC1 required
Device Trigger	DT	optional

APPENDIX W

COMPARISON OF GPIB SUBSET REQUIREMENTS/RECOMMENDATIONS

The following is a comparison of the GPIB subset requirements specified in MIL-T-28800 (Appendix D), the U.S. Air Force MATE requirements (Appendix E), and the recommendations provided by Mr. Edward Greer and Mr. Richard Calhoun (Appendix V):

1. Source Handshake. SH1 required by all sources.
2. Accepter Handshake. AH1 required by all sources.
3. Talker or Extended Talker.
   a) T1 required by MIL-T-28800.
   b) T1, T2, T5, or T6 (or corresponding TE subset) required by all other sources.
4. Listener or Extended Listener.
   a) L1 required by MIL-T-28800.
   b) L0 not allowed by all other sources. This implies L1, L2, L3 and L4 (and corresponding LE subsets) are acceptable.
5. Service Request.
   a) SR1 required by MIL-T-28800, Mr. Calhoun and Mr. Greer.
   b) SR1 optional for USAF MATE.
6. Remote-Local.
   a) RL1 required by MIL-T-28800
   b) RL1 preferred, RL2 not preferred by all other sources.
7. Parallel Poll. Considered optional or not required by all sources.
8. Device Clear.
   a) DC1 not required or considered optional by MIL-T-28800 and USAF MATE.

b) DC1 required by Mr. Calhoun and Mr. Greer.

9. Device Trigger.

   a) DT1 not required or considered optional by MIL-T-28800 and USAF MATE.

   b) DT1 required by Mr. Calhoun and Mr. Greer.

LIST OF REFERENCES

1. National Security Industrial Association, Industry/Joint Service Automatic Testing Project (I/JSATP) Final Report (1981), 27 February 1981.

2. In person interview, LCDR Stahler with Mr. Paul Willenborg and Mr. Edward Greer, NATC Code TS-243, 24 February 1983.

3. Foley, Michael, "GPIB/Diagnostic Testing," presentation at AC/D Conference, Dallas, Texas, 29 March 1983.

4. Speary, Edwin, "Mobile Automated Calibration Laboratory," presentation at the AC/D Conference, Dallas, Texas, 30 March 1983.

5. Telephone conversation between LCDR Stahler and Mr. James Langanke, NAVAIR 41731, of 10 May 1983.

6. Glassman, Jerry, Intervals By Exception, paper presented at the Standards Laboratory Conference, Washington, D.C., 15-17 June 1970.

7. Stimpsle, Fred, Calibration Interval Concepts and Practices, paper presented at the NATC Calibration Laboratory Management Review Meeting, NAS Patuxent River, 25-28 March 1980.

8. Telephone conversation between LCDR Stahler and Mr. Gary Costanzo, MEC Code 5201A, 09 March 1983.

9. In person interview, LCDR Stahler with AXC Layser, AIMSO Code 30, 24 February 1983.

10. Telephone conversation between LCDR Stahler and AXC Layser, AIMSO Code 30, 07 April 1983.

11. Memorandum from Mr. Robert Strahorn, NAEC 92524, to LCDR Stahler, 28 April 1983.

12. Naval Material Command Instruction 4790.25, Policy and Responsibility for Management of Test, Measuring and Diagnostic Equipment (TMDE), 10 July 1981.

13. Ibid., pg. 10.

14. Ibid., pp. 4-6.

15. In person interview, LCDR Stahler with Mr. Tony Buttim, NAVAIR Code 55223, 22 February 1983.

16. In person interview, LCDR Stahler with Mr. George Bednar, NAVELEX Code 8152, 22 February 1983.

17. Telephone conversation between LCDR Stahler and Mr. Robert Strahorn, NAEC Code 92524, 21 March 1983.

18. Telephone conversation between LCDR Stahler and Mr. Charles Marriott, NAVSUP Code 0139, 18 April 1983.

19. Telephone conversation between LCDR Stahler and Mr. Earl Hampel, COMNAVAIRLANT Code 532B1, 20 April 1983.

20. Memorandum from Mr. Charles Marriott, NAVSUP Code 0139, to LCDR Stahler, 19 April 1983.

21. Telephone conversation between LCDR Stahler and Mr. Earl Hampel, COMNAVAIRLANT Code 532B1, 19 April 1983.

22. Telephone conversation between LCDR Stahler and Mr. Thomas Ingram, NAVSEA Code 06C1C, 23 March 1983.

23. In person interview, LCDR Stahler with Mr. William Dunn, NESEA Code 026 (Bendix), 25 February 1983.

24. Institute of Electrical and Electronic Engineers, _IEEE Standard Digital Interface for Programmable Instrumentation_, ANSI/IEEE-Std 488-1978, New York, 1978.

25. Hewlett-Packard Co., _Electronic Instruments and Systems Catalog, 1983_.

26. Tektronix, Inc., "A Vital Link In Instrument Systems: The General Purpose Interface Bus (GPIB)," 1980.

27. Tektronix, Inc., _Products Catalog, 1983_.

28. John Fluke Manufacturing Co., _Fluke Catalog, 1982-1983_.

29. Telephone conversation between LCDR Stahler and Mr. William Dunn, NESEA Code 026 (Bendix), 24 March 1983.

30. Tektronix, Inc., "IEEE-488 Instrumentation Designed for Easy System Development," 1982.

31. Tektronix, Inc., "Tektronix Codes and Formats for GPIB Instruments," 1981.

32. Telephone conversation between LCDR Stahler and CAPT. Allen, USAF MATE Office, Code ASD/AEGB, of 09 March 1983.

33. Telephone conversation between LCDR Stahler and Mr. Harry Davis, Kelly AFB, Code SA/ALC-MMTM, 16 February 1983.

34. Telephone conversation between LCDR Stahler and Mr. Richard Pribyl, U.S. Army Communications-Electronics Command (CECOM), Code PM-TMOD, Fort Monmouth, N.J., 24 January 1983.

35. Telephone conversation between LCDR Stahler and Mr. Ralph Compton, NAVELEX Code 8151, 11 April 1983.

36. Telephone conversation between LCDR Stahler and Mr. George Bednar, NAVELEX Code 8152, 13 April 1983.

37. Telephone conversation between LCDR Stahler and Mr. Tony Butrim, NAVAIR Code 55223, 11 April 1983.

38. Telephone conversation between LCDR Stahler and Mr. Thomas Ingram, NAVSEA Code 06C1C, 11 April 1983.

39. Telephone conversation between LCDR Stahler and Mr. Adam Stiel, MEC Code 50CM, 30 November 1982.

40. John Fluke Manufacturing Co., "7405A Automated Calibration System," 1980.

41. Telephone conversation between LCDR Stahler and Mr. Jerry Hayes, MEC Code 50, 10 February 1983.

42. Telephone conversation between LCDR Stahler and Mr. Adam Stiel, MEC Code 50CM, 27 January 1983.

43. Telephone conversation between LCDR Stahler and Mr. Richard Calhoun, MEC Code 5301, 29 November 1983.

44. Telephone conversation between LCDR Stahler and Mr. Richard Calhoun, MEC Code 5301, 01 April 1983.

45. Telephone conversation between LCDR Stahler and Mr. Paul Willenborg, NATC Code TS-243, 24 November 1982.

46. Telephone conversation between LCDR Stahler and Mr. Edward Greer, NATC Code TS-243, 06 April 1983.

47. Telephone conversation between LCDR Stahler and Mr. Pat Loos, NWS Concord, Weapons Quality Engineering Division, Code 373, 12 April 1983.

48. Telephone conversation between LCDR Stahler and Mr. Jerry Glassman, MEC, 04 May 1983.

49. Riebe, Harry, "Modular/Structured Programming," presentation at AC/D Conference, Dallas, Texas, 29 March 1983.

50. Telephone conversation between LCDR Stahler and Mr. Juan Moore, Tektronix, Inc., 28 February 1983.

51. In person interview, LCDR Stahler with Mr. Ralph Compton, NAVELEX Code 8151, 22 February 1983.

52. Department of Defense, Armed Forces Procurement Regulation, para. 3-213, 01 July 1976.

53. Telephone conversation between LCDR Stahler and Mr. Joseph Siedlecki, NAVELEX Code 08T2, 06 April 1983.

54. Naval Material Command Instruction 5430.52A, Classification and Assignment of Electronic Test Equipment (ETE), 27 May 1980.

55. Tilden, Mark and Ramirez, Bob, "Understanding IEEE-488 Basics Simplifies System Integration," Tektronix Corp. reprint from EDN, 09 June 1982.

56. Weinschel Engineering Co., Inc., Short Form Catalog, 1982.

57. Telephone conversation between LCDR Stahler and Mr. Julius Trager, Hewlett-Packard Reliability Engineering Division, Stanford Park, CA., 25 April 1983.

58. Telephone conversation between LCDR Stahler and Mr. Jack Stoll, Tektronix Environmental Testing Division, Beaverton, OR., 28 April 1983.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93940	2
3.	CDR John Hall AIR-417 Naval Air Systems Command Hq. Washington, D.C. 20361	3
4.	Professor J.W. Creighton Code 54CF Naval Postgraduate School Monterey, CA 93940	1
5.	LCDR William D. Stahler 1608 Ellsberg Court Virginia Beach, VA. 23464	2
6.	Naval Air Systems Command Code 552 Washington, D.C. 20361	1
7.	Naval Electronic Systems Command Code 08T Washington, D.C. 20361	3
8.	Mr. Thomas Ingram Code 06C1C Naval Sea Systems Command Washington, D.C. 20362	1
9.	Commander, Naval Air Force, U.S. Atlantic Fleet Code 53 Naval Air Station Norfolk, VA 23511	1
10.	Commander, Naval Air Force, U.S. Pacific Fleet Code 74 NAS North Island San Diego, CA 92135	1
11.	Commander, Surface Force, U.S. Atlantic Fleet ATTN: LCDR John Reynolds Code 442 Norfolk, VA 23511	1
12.	Mr. Walter Fitzgerald Code 332 Naval Aviation Logistics Center Naval Air Station Patuxent River, MD. 20670	1

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93940	2
3.	CDR John Hall AIR-417 Naval Air Systems Command Hq. Washington, D.C. 20361	3
4.	Professor J.W. Creighton Code 54CF Naval Postgraduate School Monterey, CA 93940	1
5.	LCDR William D. Stahler 1608 Ellsberg Court Virginia Beach, VA. 23464	2
6.	Naval Air Systems Command Code 552 Washington, D.C. 20361	1
7.	Naval Electronic Systems Command Code 08T Washington, D.C. 20361	3
8.	Mr. Thomas Ingram Code 06C1C Naval Sea Systems Command Washington, D.C. 20362	1
9.	Commander, Naval Air Force, U.S. Atlantic Fleet Code 53 Naval Air Station Norfolk, VA 23511	1
10.	Commander, Naval Air Force, U.S. Pacific Fleet Code 74 NAS North Island San Diego, CA 92135	1
11.	Commander, Surface Force, U.S. Atlantic Fleet ATTN: LCDR John Reynolds Code 442 Norfolk, VA 23511	1
12.	Mr. Walter Fitzgerald Code 332 Naval Aviation Logistics Center Naval Air Station Patuxent River, MD. 20670	1

13. Mr. Jerry Hayes 2
Metrology Engineering Center
Naval Weapons Station, Seal Beach,
Pomona Annex
P.O. Box 2436
Pomona, CA. 91769

14. Mr. Donald Tobey 1
Science Applications, Inc.
1330 River Bend Drive
Suite 100
Dallas, Texas 75247

15. Mr. Merle Hollinger 1
Code 026
Mail Stop 40
Naval Electronics Systems Engineering Activity
St. Inigoes, MD 20684

16. Mr. Paul Willenborg 1
Naval Air Test Center
Code TS-243
Naval Air Station
Patuxent River, MD. 20670

17. Mr. Cliff Oehlmann 1
MLSE
Guidance and Metrology Center
U.S. Air Force Base
Newark, OH. 43055

18. Mr. Thomas Leedy 1
Electrosystems Division
National Bureau of Standards
Washington, D.C. 20234

19. Commanding Officer 1
Naval Weapons Support Center
Bldg. 41 NE
Code 70721
Attn: Mr. Larry Sollman
Crane, Indiana 47522

20. Mr. Richard Anderson 1
Code 3022
Naval Aviation Logistics Center
Detachment West
NAS North Island
San Diego, CA 92135

21. Mr. Vernon Marsh 1
Code 3012B3
Naval Aviation Logistics Center
Detachment East
Naval Air Station
Norfolk, VA. 23511

22. Aircraft Intermediate Maintenance 1
Support Office (AIMSO)
Code 30
Naval Air Station
Patuxent River, MD 20670

202533

Thesis
S6714 Stahler
c.1 General purpose
electronic test
equipment (GPETE)
acquisition considerations for automated calibration.